# The Journal of Bone and Joint Surgery

*The Official Publication of*
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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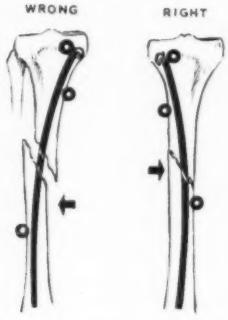
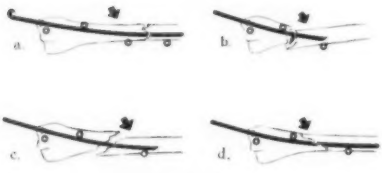


Direction of pin insertion determines compression or distraction.



**V (victory) = Good Compression**

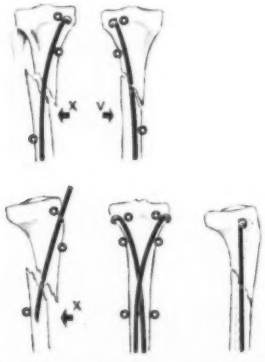
**X (no good) = Distraction**

### RADIUS

Length of fragment and direction of fracture line determine angle of pin insertion.

### RULE

Axis of pin should be same direction as axis of fracture line, intersecting to make a "V" instead of an "X".




### TIBIA

In fracture (lower left), double pins required because "V" cannot be accomplished.

* Rush, Leslie V.; Fracture Problems, Mississippi Doctor, Vol. 36, No. 10, March 1959.



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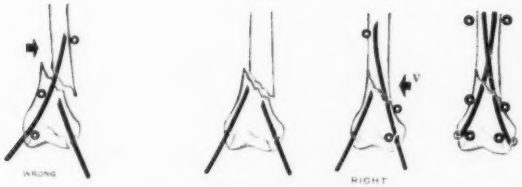
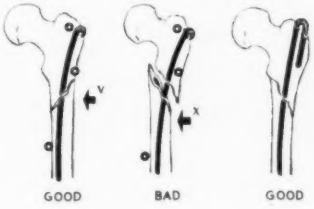


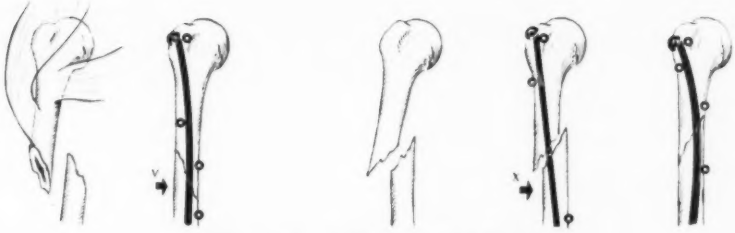

## LOWER FEMUR

Double pins required. Introduce most effective pin first.

## UPPER FEMUR

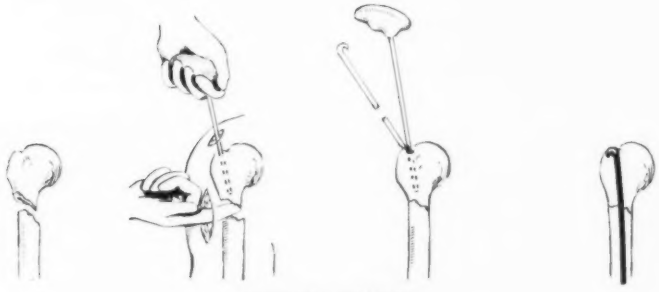
Dependent upon direction of fracture line, special type pin might be indicated.



## HUMERUS, BELOW DELTOID

Requires precise handling for good healing. For fracture at right use large curved pin for compression.



## UPPER THIRD

To avoid angulation, insert pin axially in short fragment.

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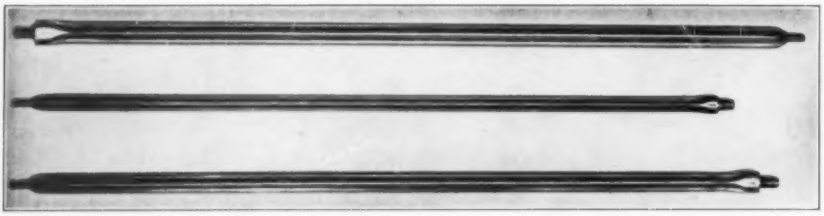

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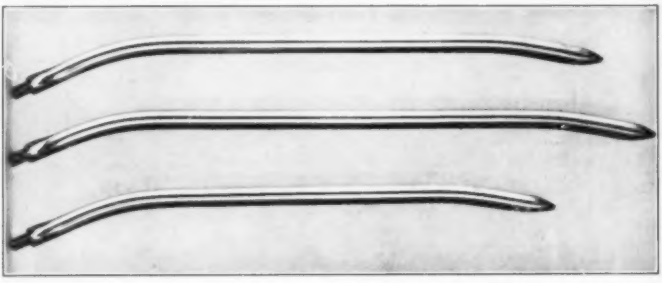

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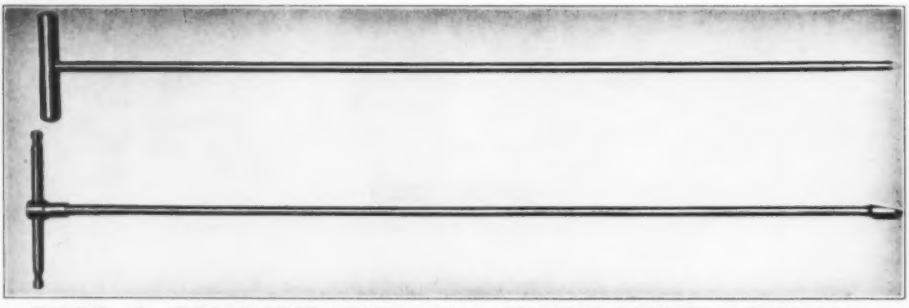

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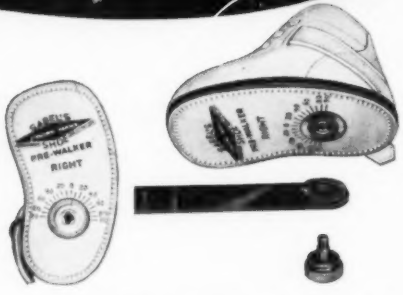


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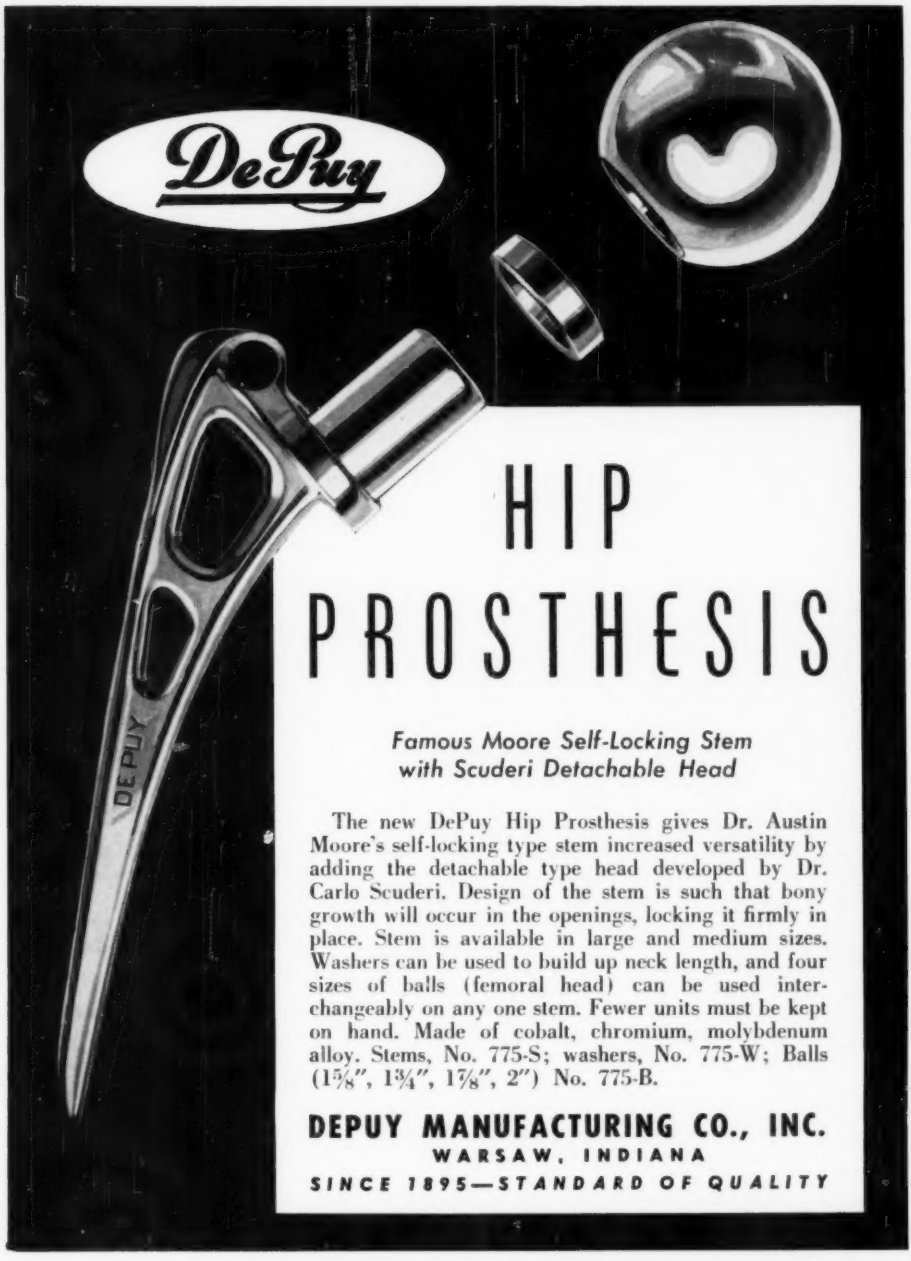


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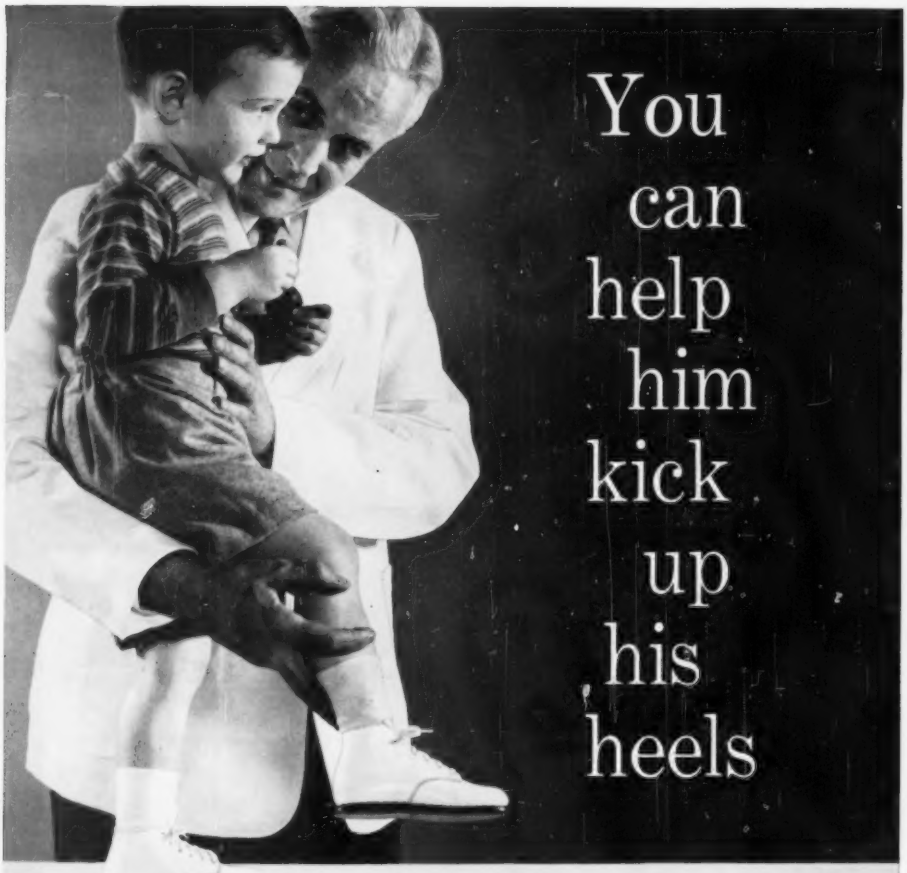



Babies are bundles of activity. As they grow, they channel their energy into pulling, pushing, crawling, and finally, one triumphant day, they're walking. If it's one of 'your' babies, you're just as proud as parents when you see a child running on strong legs and sturdy feet.

Edwards is proud as parents, too, because so many children learn to run and romp in Edwards shoes. Edwards dealers carry the three types of shoes shown below for all kinds of growing feet.

Edwards

*Recommend and prescribe* Edwards *shoes for 'your' babies. For more information, send for* Edwards *brochure and prescription blanks.*

PEDIC

PRONA-PEDIC Edwards P P

*The Shoe for Children, Philadelphia 7, Penna.*

Edwards Toddins—for beginners, the tiny tots just learning to navigate.

Edwards Pedics—for children with foot disorders that you prescribe for.

Edwards Regulars — for normal healthy children's feet—with emphasis on proper fit.

Richards

CRAIG
ADJUSTABLE
HIP SPLINT
(Patent Pending)

*For the treatment of:*

CONGENITAL DYSPLASIA
AND DISLOCATION
OF THE HIP

In the treatment of congenital dysplasia and dislocation of the hip under two years, an ideal splinting position is with the hips at 90° flexion and 90° abduction.

Tubular shaped when on the patient, the Craig Adjustable Hip Splint holds the hips comfortably in this correct position without rigid or bulky immobilization. It is impervious to water, thus completely sanitary. Constructed of frosty white plastic with plastic covered foam rubber binding to prevent irritation. The splint retains the diapers, eliminating the need for safety pins. Two snap-button fasteners makes diaper changing easy.

By a simple "button-hole" adjustment, the splint is suitable for all infants from birth to two and one-half years.

WRITE FOR FULL INFORMATION

Richards
MANUFACTURING CO.
756 Madison Avenue, Memphis, Tennessee

# "It is actually difficult to find the threads in a Gypsona Plaster Bandage"

A deeply-buried fabric that molds firmly around protuberances and *indentations,* a plaster that feels almost like pure cream in your hands, a cast with the glint of polished marble—these and other refinements continue to set Gypsona* apart

CONSIDER why this particular plaster bandage is the more prominent in a majority of the world's hospitals. Why is it the choice of so many noted orthopedic surgeons.

The reason is one of classic simplicity. Gypsona technique goes beyond "selling features", such as strength, price and the like.

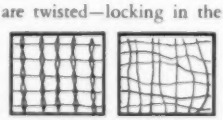
### A Matter of Total Quality

This is one of those all too few cases where a manufacturer is intent on total quality. Where he concentrates not on a competitive plus, but on every characteristic vital to casts and their effective fracture treatment.

### A Different Twist

The leno fabric, for instance. It was developed for a number of reasons. For conformability. To prevent the sliding of threads. To hold more plaster. To eliminate the sawtooth edge.

Instead of a simple crosshatch weave, two (rather than one) longitudinal threads are twisted—locking in the horizontal thread. Giving you an extraordinary conformability. You can mold a Gypsona Plaster Bandage around bones, protuberances—even identations! A rare advantage, indeed, in the treatment of fractures.



THE LENO WEAVE — ORDINARY CROSSHATCH WEAVE

### The Plaster is Sewn In

With this leno weave, every thread is anchored. All but eliminates the nuisance of "sliding threads". A high plaster content is retained. Sewn in, so to speak.

As one eminent orthopedic surgeon remarked, "Unlike other bandages, it is actually difficult to find the threads in Gypsona."

### "The Cream of Plaster Bandages"

Quarried and processed in England, Gypsona plaster is of a finely-ground texture. Only your hands can appreciate fully the soft compatibility of such a gritless plaster. You dip and then you *squeeze the wet bandage gently, tenderly.* Leave the hard wringing to the more coarse plasters. "It's the cream of the plaster bandage crop" is how a surgeon in South Africa put it.

### Reduces Temptation

Four to five minutes is the routine setting time. (For many, this short, precise setting represents a sort of challenge.) You don't have to hold the limb as long. And, incidentally, such celerity reduces the temptation to add "one more bandage".



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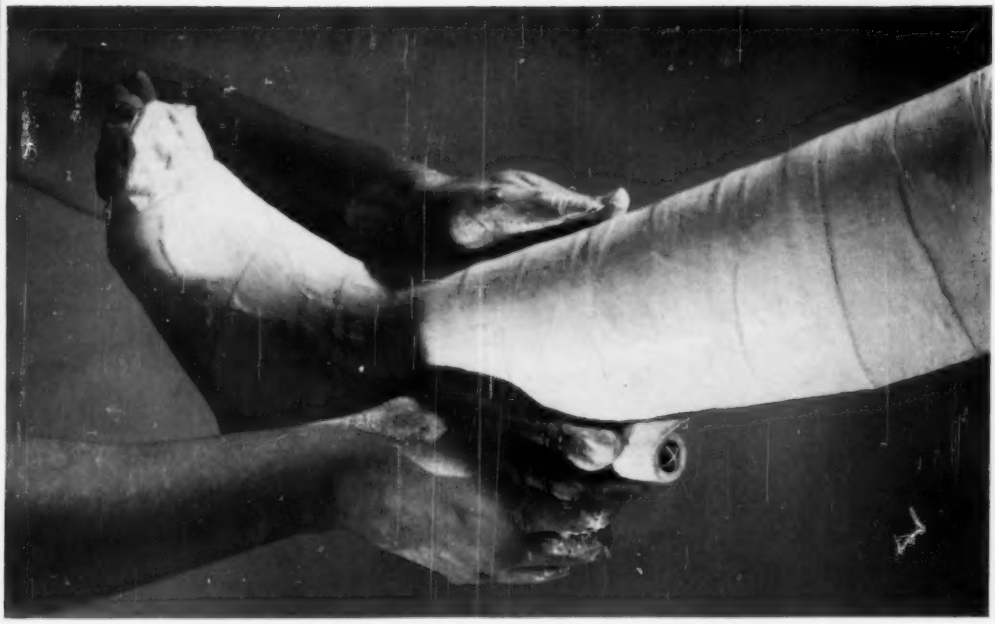

### Light, Strong and Mobile

The upshot is a light cast. Light, strong and mobile. Patients are inclined to use the limb a little more freely. You can look for a somewhat faster rehabilitation when you use Gypsona.

### A Marble-like Luster

Worth noting, too, is the fact that the cast never comes out looking like divinity fudge. The finished cast has a marble-smooth cleanness. Patients can feel reasonably neat in appearance. Ordinary soiling is easily wiped or washed away.

### Plastic Core and Airtight Package

Not to be overlooked is the ease of unwinding with the Gypsona plastic core. Prevents "telescoping". And then there's the airtight package. Plaster stays fresh almost indefinitely. You have no pre-setting problem.

### A Broad Versatility

As you would expect, a Gypsona bandage costs more. Only a few cents per cast, however. In return, you receive a bandage that performs *all* the functions unusually well. And, with uncommonly broad versatility.

Interested? Get in touch with your Bauer & Black representative. He's the man who brings the Gypsona Plaster Bandages to America.

**FREE BOOK**

"Gypsona Technique", textbook of modern plaster methods, 140 illustrations. Write Bauer & Black, 309 W. Jackson Blvd., Chicago 6, Ill.

**Curity®/Gypsona* PLASTER BANDAGES**

Bauer & Black
DIVISION OF THE KENDALL COMPANY

*Reg. T. M. of T. J. Smith and Nephew Ltd.



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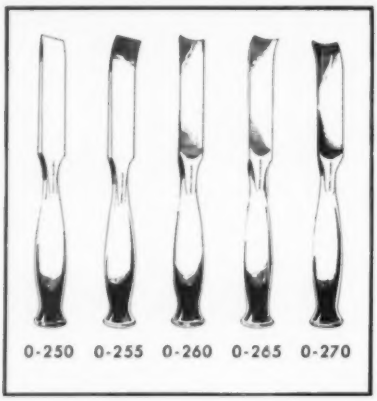
## SMITH-PETERSEN OSTEOTOMES and GOUGES



0-250 0-255 0-260 0-265 0-270

**0-250** SMITH-PETERSEN OSTEOTOME—straight, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

**0-255** SMITH-PETERSEN OSTEOTOME—curved, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

**0-260** SMITH-PETERSEN GOUGE—straight, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

**0-265** SMITH-PETERSEN GOUGE—curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

**0-270** SMITH-PETERSEN GOUGE—reverse curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

## A NEW STAINLESS STEEL CASE TO HOLD SMITH-PETERSEN OSTEOTOMES and GOUGES

0-295 Open

**CASE 0-295**—holds seven Smith-Petersen Osteotomes.

**CASE 0-296**—holds seven Smith-Petersen Gouges.

**CASE 0-297**—holds a combination of seven Osteotomes and Gouges.

**Cutting edges are protected at all times. Complete unit may be autoclaved.**

0-295 Closed

*Specify Width of Gouges and Osteotomes When Ordering*

CS ESTABLISHED 1834

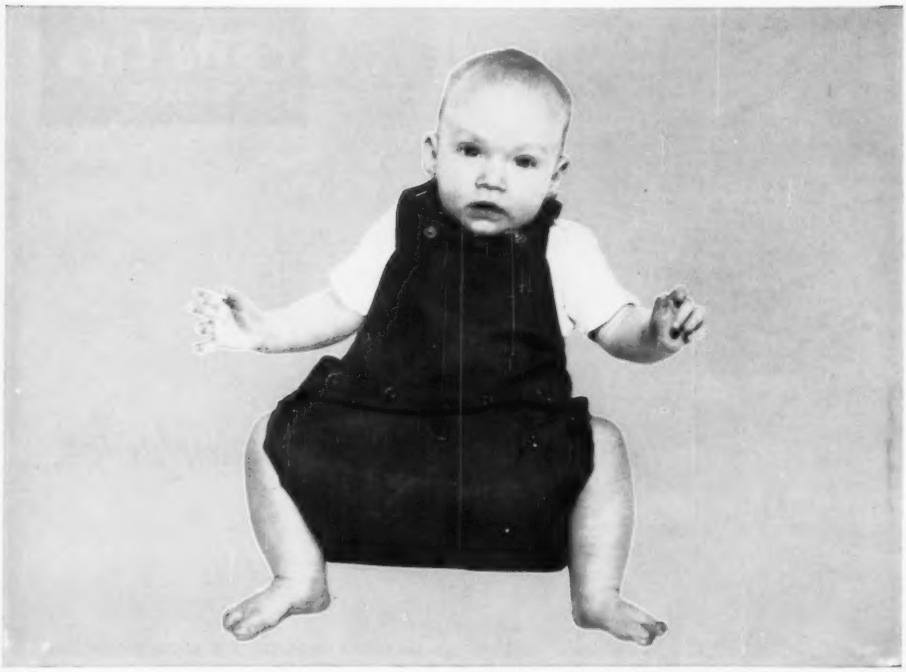
Codman & Shurtleff, Inc.

MAKERS OF SURGEONS' INSTRUMENTS

104 BROOKLINE AVENUE BOSTON 15, MASSACHUSETTS

# CAMP HIP ABDUCTION PILLOW

## *effective therapy at home*



An abduction pillow splint is a practical, atraumatic method for gradually obtaining hip abduction in infants with abduction contractors, unilateral or bilateral hip dysplasia and many cases of congenital dislocation. It is also an effective means of maintaining abduction following more severe dislocations requiring rigid immobilization or surgery. This type of pillow splint is well tolerated, permits the child to sit or stand while maintaining the abduction position.

In addition to the Camp regular Frejka type pillow this new, improved Camp pillow splint fits the contour of the legs to bring the child to frog-like position. Adjustable for leg size; a plastic water resistant pillow held in a pocket of the bib; crossed adjustable shoulder straps, all with gripper snap fasteners for easy application. Bib is made of a soft attractive cotton fabric, with extra bibs available.

Three sizes (pillow width between legs) — Small 6″, Medium 9″, Large 12″.

**S. H. CAMP and COMPANY** CAMP TRADE MARK Jackson, Michigan



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STRAIGHT LAST

REGULAR

ARCH FEATURE

MISMATES

*You'll find everything you want and need in*

*a complete line*

Here are shoes for children that adapt themselves readily to your corrective prescriptions . . . yet every shoe is styled to look like a "regular" shoe . . . freeing your patients from any inferiority complex that might develop from having to wear shoes that are "different" in appearance from those worn by other children.

For over 35 years the makers of CHILD LIFE shoes have concentrated exclusively on juvenile footwear . . . making only quality shoes of leather for both "regular" wear and orthopedic service. Nine chances out of ten there is a specially selected CHILD LIFE dealer in your community who will be glad to accept your prescription work and who is competent to handle your instructions. Write for his name, and for the CHILD LIFE service booklet for the professional man, featuring representative shoes and wedging procedures.

HERBST Shoe Manufacturing Company
Box 2005 Milwaukee 1, Wisconsin

# PROVEN EFFECTIVE FOR THE TENSE AND NERVOUS PATIENT

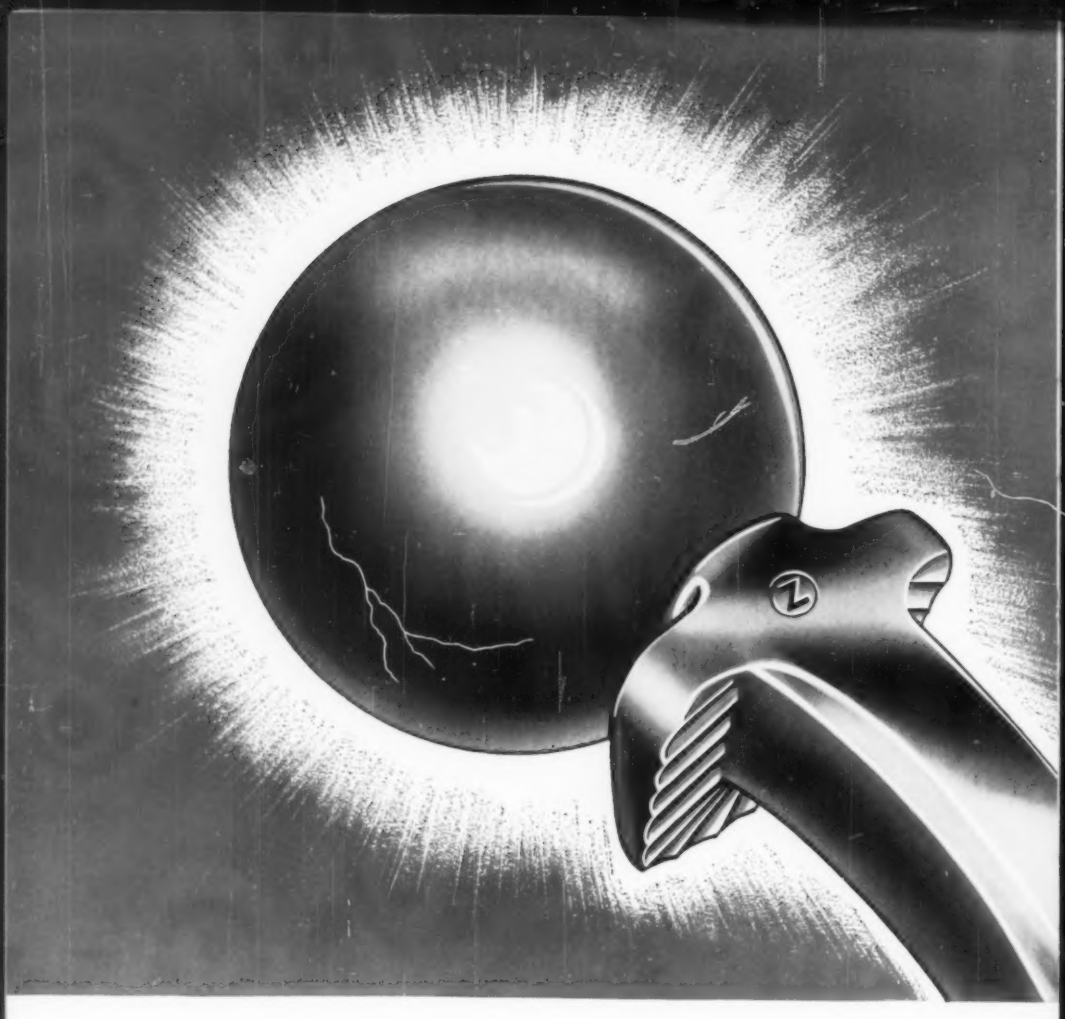
"There is perhaps no other drug introduced in recent years which has had such a broad spectrum of clinical application as has meprobamate.* As a tranquilizer, without an autonomic component in its action, and with a minimum of side effects, meprobamate has met a clinical need in anxiety states and many organic diseases with a tension component."

Krantz, J. C., Jr.: The restless patient—A psychologic and pharmacologic viewpoint. Current M. Digest 25:68, Feb. 1958.

**·Miltown®**

*the original meprobamate, discovered and introduced by*
WALLACE LABORATORIES, *New Brunswick, N. J.*

CM-215



# not even *INVISIBLE* defects get by Zimm

Before any Zimmer orthopedic appliance leaves the factory, it gets a "Zyglo-Pentrex" bath.

Designed to reveal surface flaws not visible to the eye, the Zyglo inspection is a two-step process: 1) the appliance is immersed in the chemically treated solution, and 2) then examined under "black light". Particles of the solution will adhere to invisible surface flaws and defects . . . and show up under the light. Result: not even *invisible* defects get by Zimmer inspection team. *And you get one more extra assurance that your implant appliances give completely dependable service.*

At Zimmer, testing and inspection go h in hand throughout the whole manufactu process. In addition to the Zyglo bath, an ap ance is subjected to fatigue, performa stress, strain, balance, heat rise, insulat sharpness, alignment and finish tests.

Such precise quality control is one rea that the Zimmer name has become a warra of excellence . . . and the reason you can sure Zimmer appliances add "extra" s guards to your surgery.

**zimmer®**

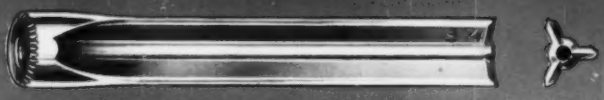
ZIMMER MANUFACTURING CO. • WARSAW, INDIANA, U.S.A.

LOOK FOR THE TRADEMARK Ⓩ

appliances for orthopedic surgery

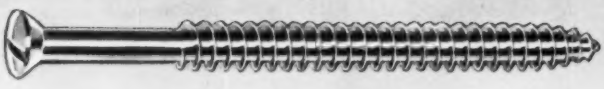
zimmer®

JEWETT PLATE AND NAIL COMBINATION NO. 472



SMITH-PETERSEN NAIL NO. 96

LORENZO SCREW NO. 970



HIP SCREW NO. 259

ZIMMER TIBIA BOLT NO. 463

MODIFIED HAGIE PIN NO. 516

KNOWLES PIN NO. 281-A

ZIMMER MANUFACTURING CO. • WARSAW, INDIANA, U.S.A.

zimmer®

LOOK FOR THE TRADEMARK (Z)

# IS THIS YOUR PATIENT?

1.

**EARLY POSTMENOPAUSE**

Complains of low back pain, vague aches and fatigue

Posture is poor

No x-ray evidence of bone lesions

2.

**LATER POSTMENOPAUSE**

Back pain is severe, spreading to hips ("girdle pain")

Patient is round shouldered, walks with a stoop

X-ray reveals compression fractures of lower vertebrae

3.

**70 AND OVER**

Fracture of hip after a minor fall

X-ray reveals fracture of neck of femur

X-ray reveals compression fractures of lower lumbar vertebrae

These three patients have osteoporosis. Early diagnosis and treatment with "Formatrix" is important because osteoporosis is probably the only age change that can be averted. With "Formatrix" therapy, relief from the symptoms of *low back pain, vague aches* and *fatigue* may be obtained in as little as a few weeks. "Formatrix" supplies the essential materials to stimulate increased bone formation and prevent further loss of bone substance that leads eventually to loss of height, stooped posture, and disabling fractures.

The highest incidence of osteoporosis may be found among the 14,000,000 women in the U.S.A. who are 55 years of age and over. Some investigators claim that almost all women past the menopause will show some degree of osteoporosis; furthermore, if all these women were examined carefully, 50 per cent would show x-ray evidence of decreased bone mass.

Suspicion may be the handiest diagnostic tool since p senting symptoms vary from mild to severe and capacitating pain, and no x-ray evidence of spinal dege eration is available until about 30 per cent of the bo matrix is lost. Between these two extremes there other signs of estrogen deficiency such as *wrinkled a thinning skin,* a *tendency to appear older than stat years;* there may also be *hypercalciuria* when postmen pausal osteoporosis is complicated by acute osteoporo of disuse.

Osteoporosis is primarily an atrophic condition of bo matrix formation and any factor that depresses oste blastic activity or retards the formation of protein a connective tissue such as *prolonged immobilization, co tisone therapy,* or *malnutrition* will favor developme of osteoporosis in both male and female.

5078

AYERST LABORATORIES
New York 16, N. Y. • Montreal, Canada

NEW

ORMATRIX" contains three most essential bone ilding materials necessary *for matrix* formation, estro- n, androgen and vitamin C.

e estrogen component of "Formatrix" stimulates teoblastic activity, thus aiding calcium and phos- orus deposition; it also imparts a feeling of "well- ing." The anabolic action of methyltestosterone pro- otes the synthesis of protein and restores a positive nitrogen balance. Together, these hormones have a greater effect on bone and protein metabolism than either alone, and side effects are minimized because of the opposing action of the two steroids on sex-linked tissues. Vitamin C plays an important role in formation of intercellular cement substance and amino acid synthesis. "Formatrix" has a large amount of vitamin C to aid in new bone matrix formation and to further help in the healing of fractures.

**"FORMATRIX"** – each tablet contains:

| | |
|---|---|
| Conjugated estrogens equine ("Premarin"®) | 1.25 mg. |
| Methyltestosterone | 10.0 mg. |
| Ascorbic acid | 400.0 mg. |

Dosage: 1 tablet a day – In the female, three weeks of treatment with a rest period of one week between courses is recommended.

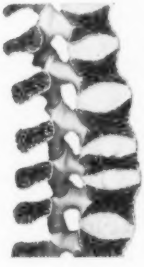
Supplied: Tablets, bottles of 60 and 500.

LITERATURE AVAILABLE ON REQUEST

1.

**EARLY POSTMENOPAUSE**
No x-ray evidence of bone lesion

2.



**LATER POSTMENOPAUSE**
X-ray reveals compression fracture of lower vertebrae

3.

**70 AND OVER**
X-ray reveals fracture of neck of femur

TO RELIEVE LOW BACK PAIN – TO PROMOTE HEALING OF FRACTURES

*in osteoporosis*

# FORMĀTRIX

(Brand of Steroid – Vitamin Combination)

*for matrix formation*



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# ANNOUNCING

The Most Important Advance
in the Construction of

**ABDUCTOR SHOES**

The Soble and Cantor Abductor Shoe maintains correction of equino-varus and treats tibial torsion and metatarsus varus in conjunction with the Denis-Browne and "A" splints.

Abduction of fore and mid foot is enforced by a considerable outflare of 30 degrees, which unlike other shoes, does not begin in the metatarsal area but originates in the talo-scaphoid and calcaneo-cuboid joint areas. The force of correction is maintained by fixing the hind foot in premolded ¾ all leather counters with the hind foot in neutral position. No deforming force is exerted on the toes because of a square toe box, providing adequate room for the fifth toe.

The Abductor Shoe holds varus correction —

(1) through hind foot valgus, built into the last with a calcaneo-cuboid lift, graduated across the plantar surface,

(2) through the heel itself with an extra broad base flared laterally, but without wedge, and by extending the outer margin of the heel to the cuboid level—preventing over-riding.

(3) through a ten iron sole with a square toe pattern insuring wider sole spread and thus resisting tendency to varus,

(4) through a shank of fifteen gauge steel which discourages tarsal and metatarsal equinus.

The features mentioned above eliminate the need for outer sole wedges, outer heel wedges, special heel additions and inner cuboid pads in most instances. The shoe itself features sharkskin tip in all sizes and Votan leather soles which are wide in the midtarsal area.

**A SAVING TO YOUR PATIENTS**

NO EXTRA CHARGE FOR MIS-MATES ON ABDUCTOR OR PLUMMET SHOES

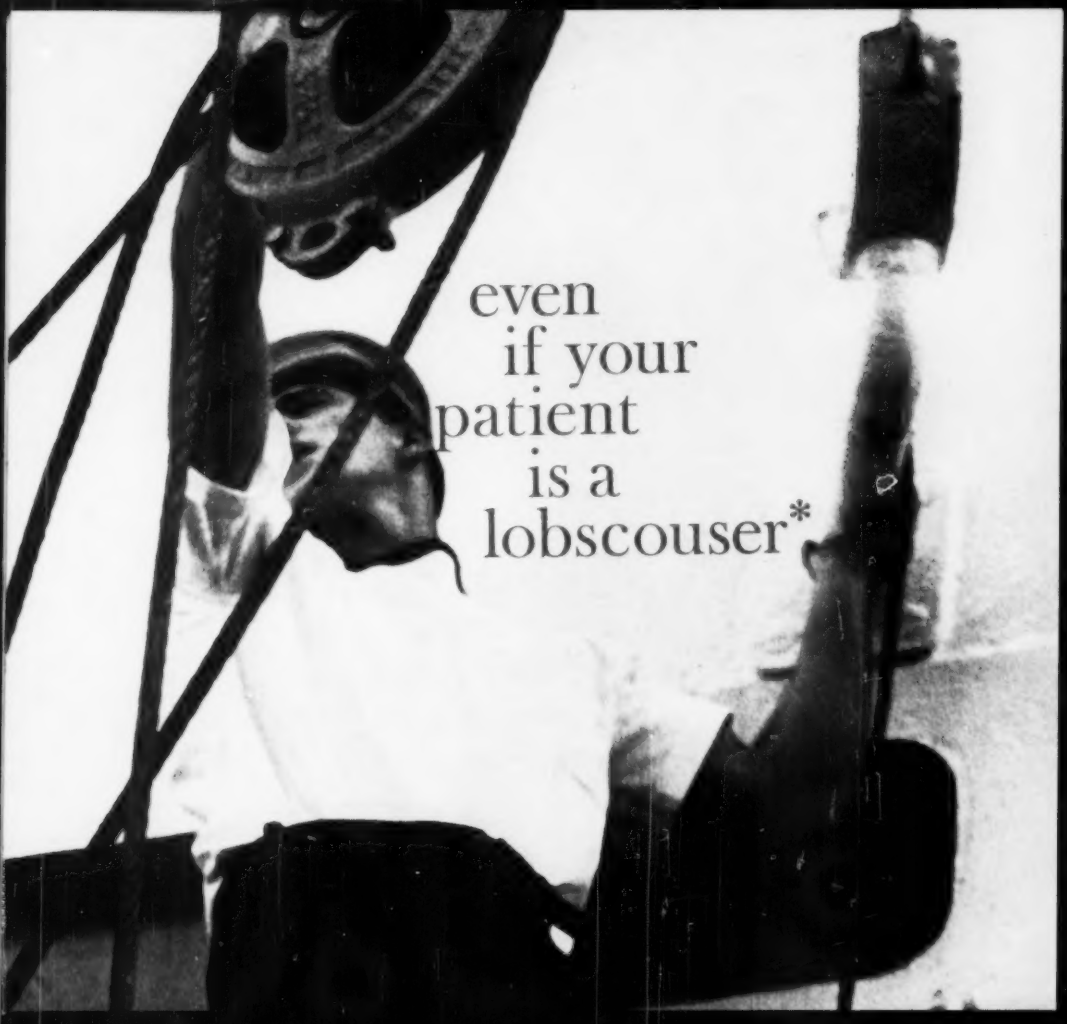
Left or Right
Any Size or Width

S and C

**SOBLE *and* CANTOR**

**1503 E. WADSWORTH AVE.**
**PHILADELPHIA 50, PA.**

J. S. ZULICK CO., Inc. • EXCLUSIVE MAKERS




'll be under way again soon, once he's on

# PARAFON®

AFLEX® + TYLENOL®)

muscle relaxation plus analgesia

d in arthritis

ARAFON®

th Prednisolone

prescribe PARAFON in low back pain—sprains—strains—rheumatic pains

Each PARAFON tablet contains:

PARAFLEX® Chlorzoxazone†.....125 mg.

Specific for skeletal muscle spasm

TYLENOL® Acetaminophen.....300 mg.

The analgesic preferred in musculoskeletal pain

*Dosage:* Two tablets t.i.d. or q.i.d.

*Supplied:* Tablets, scored, pink, bottles of 50.

Each PARAFON WITH PREDNISOLONE tablet contains: PARAFLEX® Chlorzoxazone† 125 mg., TYLENOL® Acetaminophen 300-mg., and prednisolone 1.0 mg.

*Dosage:* One or two tablets t.i.d. or q.i.d.

*Supplied:* Tablets, scored, buff colored, bottles of 36.

*Precautions:* The precautions and contraindications that apply to all steroids should be kept in mind when prescribing PARAFON WITH PREDNISOLONE.

*sailor †U. S. Patent Pending

McNEIL

Neil Laboratories, Inc • Philadelphia 32, Pa.

254483

**DOCTOR** . . . *to help your backache patients resume some of their normal, happy activities, Simmons has invented a new kind of orthopedic-type mattress* . . . **BACK CARE** *with Built-in Bedboard*

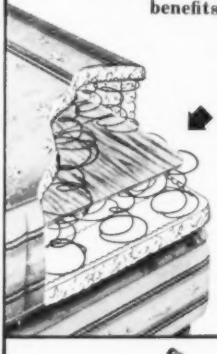
Backache is one of the more common disorders . . . and physicians have long desired a mattress especially adapted to the needs of the chronic-backache patient.

BACK CARE®, developed in consultation with orthopedic surgeons, can be an important adjunct to the management of backache and other disorders requiring a firm, comfortable sleeping surface.

*Hundreds physicians are now using Back Care in their own homes for corrective action and sleeping comfort . . . and many more recommend it for their orthopedic patients.*

For more complete information on Back Care . . . research, construction, testing . . . write to Simmons Co., Dept. BB, Merchandise Mart, Chicago, Ill., for a free copy of the descriptive Back Care booklet.

**Why the Back Care unique construction benefits many orthopedic patients**



**1.** This upper layer of 312 coils adjusts to body contours for comfort.

**2.** This built-in *plywood* bedboard keeps the spine properly aligned . . . and exerts corrective action *close up to the back* where firm support is needed.

**3.** This lower layer of springs acts as "floating" mechanism for bedboard, equalizes weight over coils and prevents "sag."

BACK CARE
WITH BUILT-IN BEDBOARD
by SIMMONS

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The up-to-date reference book on internal fixation
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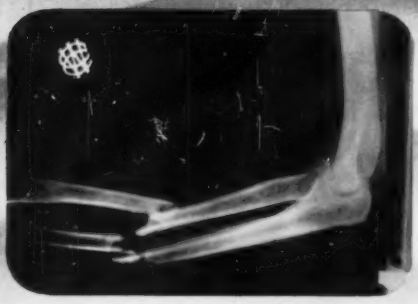
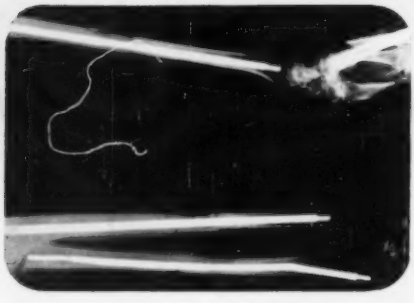
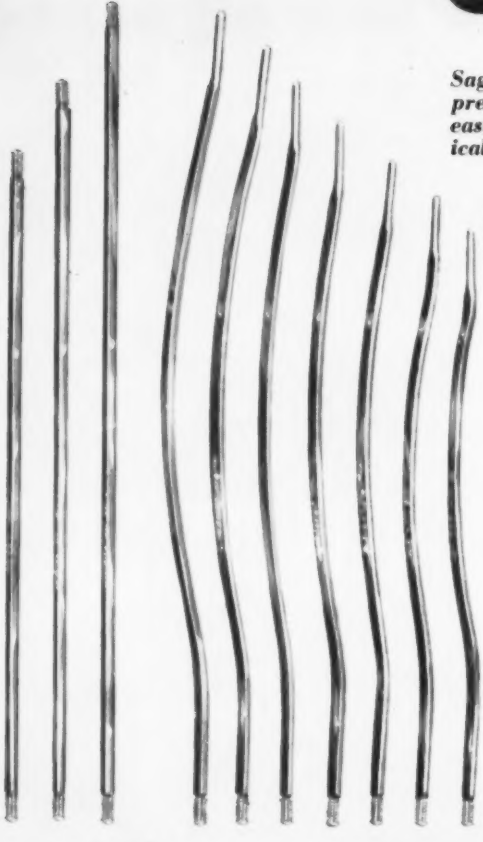




# sage pins

*Sage Triangular Forearm Pins have precision formed contours to allow easier insertion and aid in anatomical alignment.*

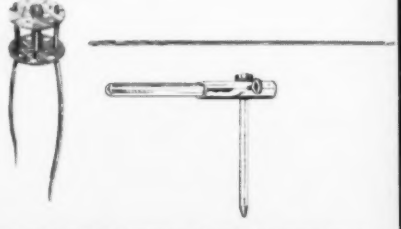


MADE OF NON-MAGNETIC, INERT, SMO STAINLESS STEEL . . . SPRING TEMPERED TO A SPECIAL ROCKWELL-HARDNESS.

Pre-formed (one end threaded) Radius Pins available in seven lengths, graduated in ½-inch increments from 8 to 11 inches. Straight (both ends threaded) Ulna Pins available in three lengths, graduated in 1-inch increments from 9 to 11 inches. Radius and Ulna Pin diameters are either 4.4 mm or 5 mm.

COMPLETE SET CONSISTS OF SEVEN RADIUS PINS, THREE ULNA PINS AND PIN HOLDING RACK.

THE REAMER DRILL AND DRIVER EXTRACTOR ARE ESPECIALLY DESIGNED FOR USE WITH THESE PINS. THE DRILLS ARE CORRECTLY SIZED TO ASSURE EASY INSTALLATION AND MAXIMUM HOLDING POWER.



WRIGHT

FOR FURTHER INFORMATION WRITE TO DEPT. W-7

MANUFACTURING COMPANY

880-882 ADAMS, MEMPHIS, TENNESSEE

RUBBER ELASTIC BANDAGE

**ASSURES MORE UNIFORM SUPPORT**

Scientifically determined number of rubber and cotton threads provides a **balanced weave** that assures optimal therapeutic results.

ACE guarantees even and controlled stretch

ACE insures firmness under tension

ACE prevents "bunching"

ACE minimizes possibility of vein constriction

**MAINTAINS ITS ELASTICITY LONGER**

Today, ACE provides your patient with anatomically correct support far longer. B-D's newly developed type of heat-resistant rubber can withstand dry heat sterilization and has a greater tensile strength than rubber found in ordinary bandages.

Now, more than ever, ACE is the name to remember. Only Becton, Dickinson and Company makes ACE rubber elastic bandage.

BECTON, DICKINSON AND COMPANY · RUTHERFORD, NEW JERSEY

B-D AND ACE ARE REGISTERED TRADEMARKS OF BECTON DICKINSON AND COMPANY

You can expect your patients with dysmenorrhea to return to normal activity when you prescribe

THE FIRST TRUE "TRANQUILAXANT"

**Trancopal®**

**case profile no. 3347*** *A 35-year-old housewife had a history of severe dysmenorrhea and premenstrual tension:* Menarche, age 14; gravida II, Para I; menstrual cycle, fairly regular; pelvic examination, essentially negative results. The patient suffered from severe tension and irritability for from two to seven days before and during menstruation. Cramps were experienced during all three days of the menstrual periods. The analgesics provided limited symptomatic relief.

*Trancopal, 200 mg. t.i.d., was prescribed for the dysmenorrhea.* Result: Relief of severe cramping and accompanying irritability. *Because of these excellent results Trancopal was prescribed for premenstrual tension.* Result: Excellent response. This patient has remained on the above regimen for more than six months and no adverse effects have been noted.

*Indications*— Musculoskeletal: Low back pain (lumbago, sacroiliac pain, etc.); neck pain (torticollis); bursitis; rheumatoid arthritis; osteoarthritis; disc syndrome; fibrositis; ankle sprain; tennis elbow; myositis; postoperative muscle spasm. Psychogenic: Anxiety and tension states; dysmenorrhea; premenstrual tension; asthma; angina pectoris; alcoholism.

*Dosage:* 100 or 200 mg. orally three or four times daily. Relief of symptoms occurs in fifteen to thirty minutes and lasts from four to six hours.

*How Supplied:* Now available in two strengths. Trancopal Caplets®, 100 mg. (peach colored, scored), bottles of 100. New Strength—Trancopal Caplets, 200 mg. (green colored, scored), bottles of 100.

Winthrop LABORATORIES
NEW YORK 18, N.Y.

**Clinical Report on file at the Department of Medical Research, Winthrop Laboratories.*

Trancopal (brand of chlormezanone) and Caplets, trademarks reg. U.S. Pat. Off. 1406M

Louis C. Weld, President, G. W. Chesbrough Co. . . . "My own personal experience led to the development of Chesbrough Orthopedic Pre-Walkers, club-foot, open toe and closed toe Surgicals."

*"Orthopedic shoes parents can afford . . .*

## CHESBROUGH Corrective Pre-Walkers"

"When a child in my own family needed a corrective shoe, I discovered what a strain it can mean to a family budget, because 1) corrective footwear is expensive and 2) frequent purchase of new corrective shoes is required. Then and there I decided there was a real need for a moderately priced corrective shoe —a shoe parents could afford. That's why and when Chesbrough Orthopedic Pre-Walkers were born.

"Our 60 years of shoe-making experience resulted in corrective Pre-Walkers of scientific design, expert workmanship, fine leathers combined with orthopedically correct lasts to provide necessary correction at an economical price."

Today—just three years later—orthopedic specialists in 45 states and several foreign countries are prescribing these shoes.

**All shoes** in unlined white elk, sizes 000 to 4, narrow and wide. Available in full pairs, split pairs or single shoes (no extra charge for half pairs).

**No. 1400 OPEN TOE.** Straight-line symmetrical last, firm heel, no back seam. Adaptable to Denis Browne Splints.

**No. 1700 CLUBFOOT, OPEN TOE.** Special outflare last, sturdy instep strap to stabilize heel.

**No. 1300 CLOSED TOE.** Lace-to-toe design permits snug, gentle fit. Perfectly smooth inside.

**MAIL COUPON FOR FREE DESK SAMPLES**

**G. W. CHESBROUGH CO.**
807 Smith Street, Rochester 6, N. Y.

NAME.....
ADDRESS.....
CITY.....
YOUR ORTHOPEDIC SHOE DEALER:
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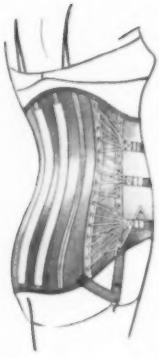
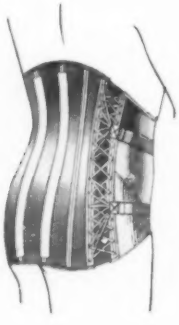
FOR
ORTHOPEDIC
APPLICATIONS

# Freeman SURGICAL SUPPORTS



**MODEL 423**
Sacro-Lumbar Back
Support for Women



**MODEL 422**
Sacro-Lumbar Back
Support For Men

For 68 years Freeman has worked closely with orthopedic surgeons to design surgical garments that provide *correct* support. Each garment is made by skilled craftsmen using the finest materials available.

There's a quality Freeman support for most every application. You can be certain that the garment you select will carry out your prescription to the best possible satisfaction of you and your patient.

Freeman corset-type back supports provide bracing in any desired degree to almost complete immobilization. Special construction features assure comfort for the wearer in sitting, standing and reclining positions.

## FREEMAN QUALITY FEATURES

New Dacron-Pima Cotton Fabric. Petal-Soft Interior Finish cushions the stays, avoids irritation. Self-Smoothing, Exclusive Non-Wrinkle Fly speeds putting on garment and avoids comfort-robbing wrinkles. Soft Plush Padding under hooks and eyes. Superb Needle Work.

*Prescribe*
**FREEMAN**
*with Confidence!*

**FREEMAN MANUFACTURING CO.**
**Dept. 710, Sturgis, Michigan**

Please send details on new Freeman features and include free reference catalog.

Name_____

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City_____ Zone____ State_____

# in your hospitalized patient

## Compazine* offers

## 4 beneficial effects

- relieves anxiety and tension
- controls nausea
- stops postoperative vomiting
- eases emotional stress that may aggravate pain and other psychosomatic symptoms

Also, hypotension is minimal and infrequent—a particular advantage in surgical patients.

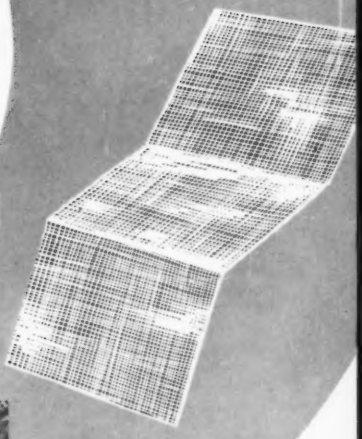
For immediate effect: Ampuls and Multiple dose vials.
Also available: Tablets, Spansule† sustained release capsules, Suppositories and Syrup.

SKF SMITH KLINE & FRENCH LABORATORIES

*T.M. Reg. U.S. Pat. Off. for prochlorperazine, S.K.F.
†T.M. Reg. U.S. Pat. Off.

# The NEW DUAL PURPOSE

VASELINE
PETROLATUM GAUZE U. S. P.
STERILE
3 x 3 PAD, opens to 3 x 9 INCHES
Fine-Mesh Absorbent Gauze (44-36)
Impregnated with White Petrolatum
CHESEBROUGH-POND'S INC.
NEW YORK 17, N.Y.
UNOPENED ENVELOPE MAY BE AUTOCLAVED OR COLD-SOAKED
TEAR HERE



## 3″ x 9 STRIP

Shorter length ends wa
on small area wounds. New Z-f
insures perfect graft tak
Guaranteed sterile at time of u

## 3″ x 3″ PAD

Three-ply, fine-mesh gauze, lightly impregnated — for use in physician's office, industrial medical department, first aid.

## 6th SIZE of VASELINE® PETROLATUM GAUZE

***Now supplied in:***

| | |
|---|---|
| 1/2″ x 72″ | 3″ x 18″ |
| 1″ x 36″ | 3″ x 36″ |
| 3″ x 3″ / 3″ x 9″ | 6″ x 36″ |

***Sole Maker:***

**CHESEBROUGH-POND'S INC.**
Professional Products Division
**New York 17, N. Y.**

VASELINE *is a registered trademark of Chesebrough-Pond's Inc.*

## In skeletal-muscle disabilities . . .

## Curbs spasm, relieves rigidity, and relaxes psychic tension

Of all muscle relaxants in current use, only meprobamate is supported by hundreds of published clinical studies that demonstrate relaxing action on both the brain and the skeletal musculature. EQUANIL reduces muscular spasm and tension, aids in the restoration of mobility, speeds rehabilitation, lessens the emotional overlay.

*Prescribe it in spasm or tension secondary to:* sprains, strains, contractures, fibrositis, myositis, low-back syndrome, frozen shoulder, cervical-rib syndrome, herniated intervertebral disk, wryneck, rheumatoid arthritis, rheumatoid or traumatic spondylitis, certain neuromuscular disorders.

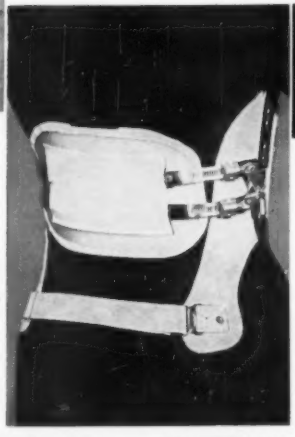
Equanil

Meprobamate, Wyeth

Wyeth Philadelphia 1, Pa.

# THE JEWETT HYPEREXTENSION BACK BRACE

This brace has proven its worth as a satisfactory hyperextension immobilization device in cases of uncomplicated compression fractures of the lower thoracic and entire lumbar spine. It maintains desired hyperextension as well or better than the best applied hyperextension plaster of paris cast. The brace weighs only a fraction of the weight of a cast, permits desired body hygiene and usually can be worn beneath ordinary garments with little or no alteration. Another advantage of the brace is its adjustability without loss of its hyperextension qualities.

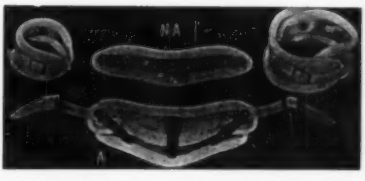


## SPINAL FUSION MODEL

The spinal fusion model has additional advantages which make it an admirable post-lower fusion brace where minimal motion in the fused area is desired.

## MYO-CERVICAL COLLAR

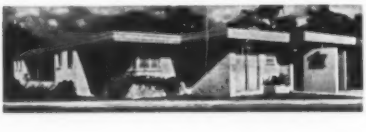
For cases such as whip-lash injuries, wry neck, torticollis, etc.; adjustable as to height and degree of extension. Lower perimeter adjusts automatically to contour of sternum and clavical. Light, cool, comfortable and washable; provides positive support. Available in small, small-special, medium and large sizes.



## EXTENSION-FLEXION COLLAR—The Universal Cervical Collar

Indicated in those conditions requiring positive support and immobilization such as whip-lash injuries, wry neck and torticollis; also as an adjunct to braces or plaster casts in certain other post-traumatic and post-operative cervical lesions. This reversible collar may be used to maintain **extension, flexion** or **stabilization;** is semi-rigid, ventilated, completely cushioned and adjustable to height, circumference and degree of extension or flexion. All parts are interchangeable and washable. Available in small, medium and large sizes with interchanging of parts to make possible eighteen various sizes by use of double buckle straps.

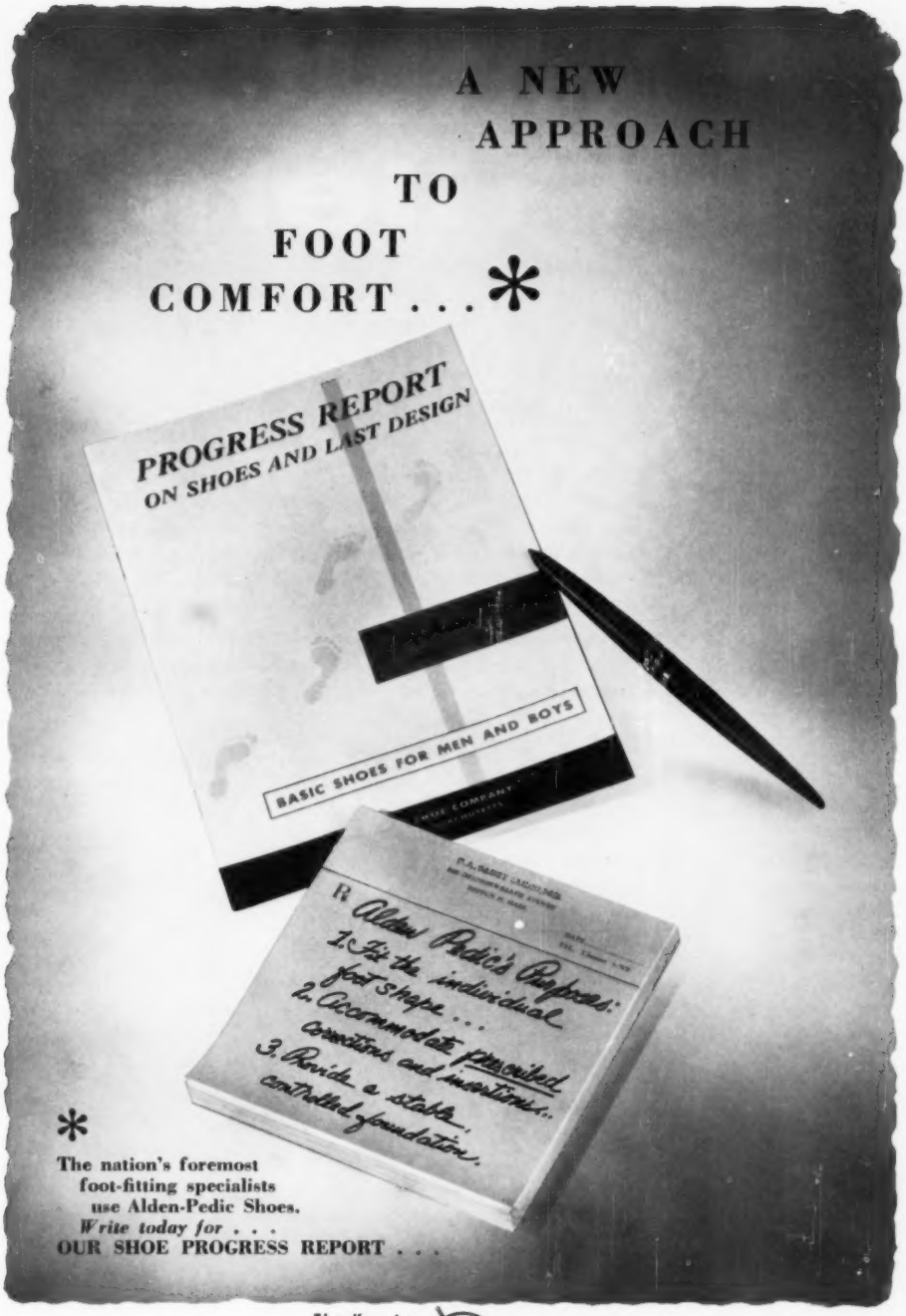
**Literature, reprints and measuring charts upon request or better still, the name and address of our nearest bracemaker-distributor.**



## FLORIDA BRACE CORPORATION

**Post Office Box 1366 • Winter Park 3, Florida**

**Phone Midway 4-2650**


A NEW
APPROACH
TO
FOOT
COMFORT . . . *
PROGRESS REPORT
ON SHOES AND LAST DESIGN
BASIC SHOES FOR MEN AND BOYS
R Alden Pedic's Purpose:
1. Fit the individual foot shape . . .
2. Accommodate prescribed corrections and inserts . .
3. Provide a stable, controlled foundation.
*
The nation's foremost foot-fitting specialists use Alden-Pedic Shoes.
*Write today for . . .*
OUR SHOE PROGRESS REPORT . . .

*The Key to*
C. H. ALDEN SHOE CO. BROCKTON, MASS.
*Foot Balance*




In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

# NOTABLY SAFE AND EFFECTIVE INHALATION ANALGESIA

## "Trilene"®

Brand of trichloroethylene U.S.P. (Blue)

SELF-ADMINISTERED WITH THE

**"Duke"® University Inhaler**

No. 3160 Model-M

With the "Duke" University Inhaler, "Trilene" analgesia can be self-administered by the patient, adult or child, under medical supervision, with a relatively wide margin of safety. Induction of analgesia is usually smooth and rapid. Inhalation is automatically interrupted if unconsciousness occurs. Outpatients can generally leave the doctor's office or hospital within 15 to 20 minutes.

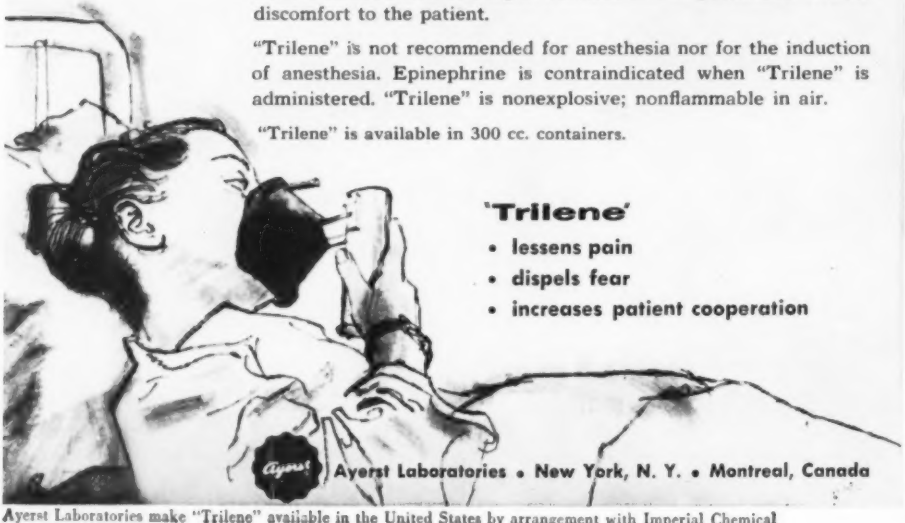
In Obstetrics . . . Self-administered "Trilene" will usually give effective relief of pain throughout labor and, for delivery, it may be employed in association with pudendal block or low spinal anesthesia.

In Pediatrics . . . The "Duke" University Inhaler is so easy to operate that even a child can administer his own "Trilene" analgesia.

In Surgery . . . With "Trilene," self-administered, many so-called "minor" yet painful procedures such as biopsies, suturing of lacerations, and reduction of simple fractures can be performed without discomfort to the patient.

"Trilene" is not recommended for anesthesia nor for the induction of anesthesia. Epinephrine is contraindicated when "Trilene" is administered. "Trilene" is nonexplosive; nonflammable in air.

"Trilene" is available in 300 cc. containers.



**'Trilene'**

- lessens pain
- dispels fear
- increases patient cooperation

Ayerst Laboratories • New York, N. Y. • Montreal, Canada

Ayerst Laboratories make "Trilene" available in the United States by arrangement with Imperial Chemical Industries Limited.

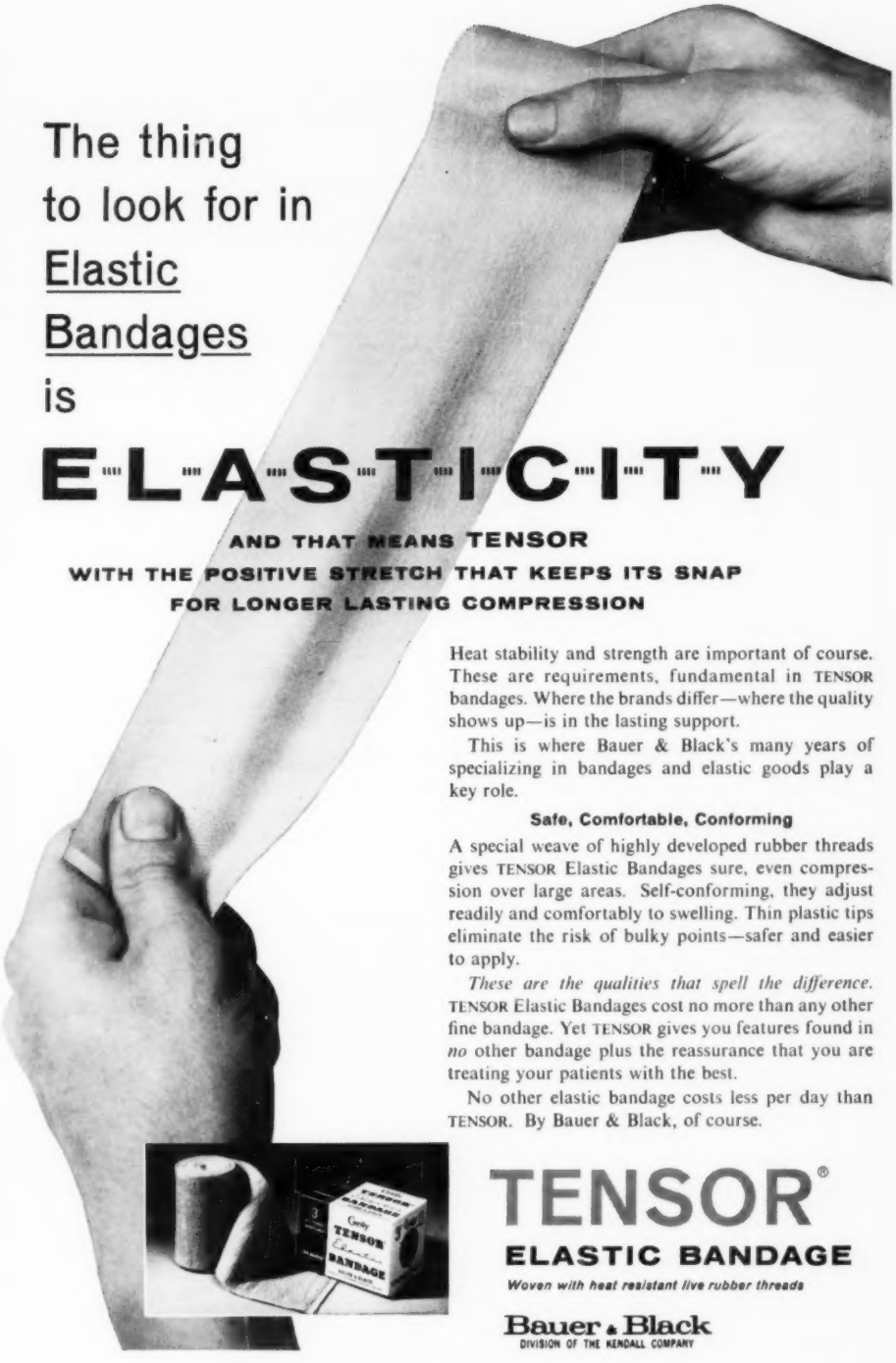
5717

The thing to look for in Elastic Bandages is

# E·L·A·S·T·I·C·I·T·Y

**AND THAT MEANS TENSOR**

**WITH THE POSITIVE STRETCH THAT KEEPS ITS SNAP FOR LONGER LASTING COMPRESSION**




Heat stability and strength are important of course. These are requirements, fundamental in TENSOR bandages. Where the brands differ—where the quality shows up—is in the lasting support.

This is where Bauer & Black's many years of specializing in bandages and elastic goods play a key role.

**Safe, Comfortable, Conforming**

A special weave of highly developed rubber threads gives TENSOR Elastic Bandages sure, even compression over large areas. Self-conforming, they adjust readily and comfortably to swelling. Thin plastic tips eliminate the risk of bulky points—safer and easier to apply.

*These are the qualities that spell the difference.* TENSOR Elastic Bandages cost no more than any other fine bandage. Yet TENSOR gives you features found in *no* other bandage plus the reassurance that you are treating your patients with the best.

No other elastic bandage costs less per day than TENSOR. By Bauer & Black, of course.

# TENSOR®

**ELASTIC BANDAGE**

*Woven with heat resistant live rubber threads*

Bauer & Black
DIVISION OF THE KENDALL COMPANY

# SAFER and QUICKER MENISECTOMIES
## with BOWEN Instruments

### Grover Meniscotome

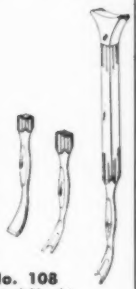
Used through any arthrotomy exposure and on either semilunar cartilage, it guarantees the integrity of all structures within the joint and permits complete removal of either meniscus.

Designed like a large intra-uterine curette, it presents a smooth rounded guard on the outer surface of the ring, the inner margin of which is a keen knife edge permitting cutting in any direction. Its use will shorten by about one-third the present operating time.

**Standard Length: 8½"** • **No. 128**

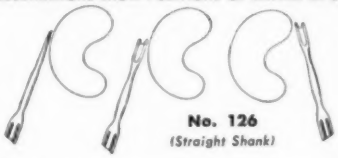
### Smillie Cartilage Sets

Designed with handles that do not obscure field of vision. Longer beak always rests on tibial table. Beaked knife divides the peripheral attachments of the medial meniscus. Also divides the central attachment of the posterior horn of the lateral meniscus. Second beaked knife used for the same purpose, also to divide the central attachment of the posterior horn of the medial meniscus. Chisel mobilizes middle third of the meniscus.



**No. 108**
*(Curved Shank)*

**ILLUSTRATIONS SHOW POSITIONS OF KNIVES IN USE**



**No. 126**
*(Straight Shank)*

**No. 108-4 90° Smillie Cartilage Knife**

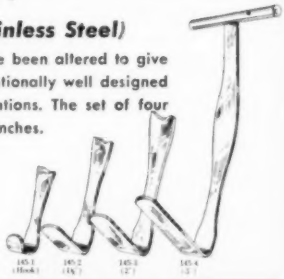
A specially curved shank to facilitate the removal of the posterior horn of the meniscus.

### Smillie Knee Joint Retractor Set *(Stainless Steel)*

The angles of the blades and the modified handles of these retractors have been altered to give a better grip and keep the fingers away from the incision. They are exceptionally well designed for the removal of menisci and for use in practically all knee joint operations. The set of four comprises one hook and three with blade lengths from 1½ inches to 3 inches.

**FEATURES:** "Sure grip handles for perfect control." • "Hardened and tempered to rigid specifications." • "Useful retractors for many other surgical procedures."

**No. 145 Knee Joint Retractor Set**
(Four Pieces)



*New!*

*Unique!*

### BOWEN Liquid DISPENSER

**For the dispensing of alcohol and other cleansing liquids.**
*Patent No. 2,752,069*

- *Quick Acting • Unbreakable • Will Not Tip*
- *Easily Operated with one hand*
- *To Use, Just Press on Metal Plate!*

**ONLY $1.50**

**No. 143**

**BOWEN & COMPANY, INC.**

**P. O. BOX 5818**
**BETHESDA, MARYLAND**

# NEW *Fillauer*

## DETACHABLE

## DENIS BROWNE NIGHT SPLINT

### STREAMLINED and IMPROVED

1. Precision die cast Serrated Discs permit 50 positions.
2. New Knurled Screw locks discs in position.
3. New Triple Flange fits club foot shoes or any sole thickness.
4. Streamlined Wing Screw secures flange to shoe sole.
5. Durable, attractive red alumilite color on bars.
6. Lengths 6, 7, 8, 9, 10, 12, 14, 16 and 18 inches. Special lengths to 30 inches at no extra cost.

ORTHOPEDIC SURGEONS recognize the decided advancements this versatile splint affords in treating club feet, positional deformities, tibial torsions, flat feet and congenital hip dislocations. Also applicable for any other deformities that are actively corrected by incessant kicking.

Very little adjustment by surgeon or orthotist is required to fit and position this new Fillauer Detachable Splint.

Pre-walker or larger surgical and club foot shoes work extremely well with the Fillauer Splint. Outgrown shoes may be used by cutting out toes.

*Fillauer* SURGICAL SUPPLIES, INC.
BOX 1678 CHATTANOOGA, TENN.
*ESTABLISHED 1914* *Manufacturers of Orthopedic Supplies*

ORTHOPEDIC APPLIANCE & LIMB MANUFACTURERS ASSN. AMA

Stryker

# Screwdriver and Colorguide Drill

*Handpieces for the Stryker Electro-Surgical Unit . . .*

- Bone Saw
- Rolo-Dermatome
- Sagittal Saw
- Pencil-Grip Burring Handpiece
- Bone Drill Handpiece
  - Automatic Screwdriver
  - Colorguide Drill
  - Jacobs Chuck
- Colorguide Screw Case

**Screws are driven in automatically. Color-coded drill determines depth of hole.**

The lightweight handpiece is geared to slow speed and operates not only the Drill and Screwdriver, but also a ¾" Jacobs Chuck. The colorguide on the drill shaft accurately indicates the depth of hole drilled for quick selection of correct screw length by color from screw case.

Screws are inserted or removed by using the clockwise or counter-clockwise shaft in the drill head.

Ask for the Colorguide Drill and/or Screwdriver on approval. Call, wire or write today.

Stryker

SURGICAL AND HOSPITAL EQUIPMENT

Orthopedic Frame Company

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Exclusive Agent for Export: Schueler & Co., 75 Cliff St., N. Y.

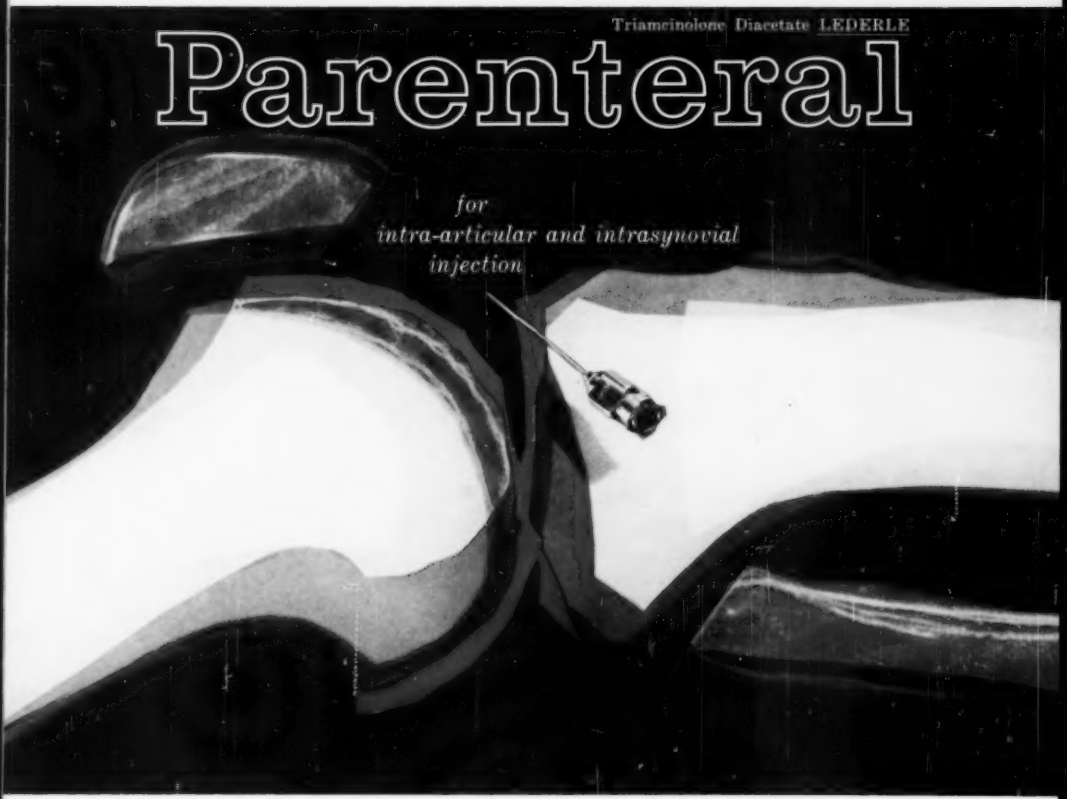
ESTABLISHED 1914 Manufacturers of Orthopedic Supplies

# New Aristocort®

Triamcinolone Diacetate LEDERLE

# Parenteral

*for intra-articular and intrasynovial injection*



for *longer* and *more pronounced* anti-inflammatory action in the *shortest time*

- when systemic therapy is contraindicated
- when systemic corticosteroids produce serious side effects
- to secure quick relief in one or two joints
- for use in conjunction with orthopedic procedures

*Indications:* rheumatoid arthritis; osteoarthritis; bursitis; peritendinitis; ganglion; intermittent hydroarthrosis; epicondylitis and related conditions.

ARISTOCORT Parenteral contains: 25 mg. per cc. of ARISTOCORT® Triamcinolone Diacetate micronized; polysorbate 80 U.S.P. 0.10%; benzyl alcohol 0.95%; benzalkonium chloride 0.01%; sorbitol solution N.F. 84.83%, and water for injection q.s. 100%.

All precautions required for intra-articular and intrasynovial administration of other corticosteroids should also be observed with ARISTOCORT Parenteral.

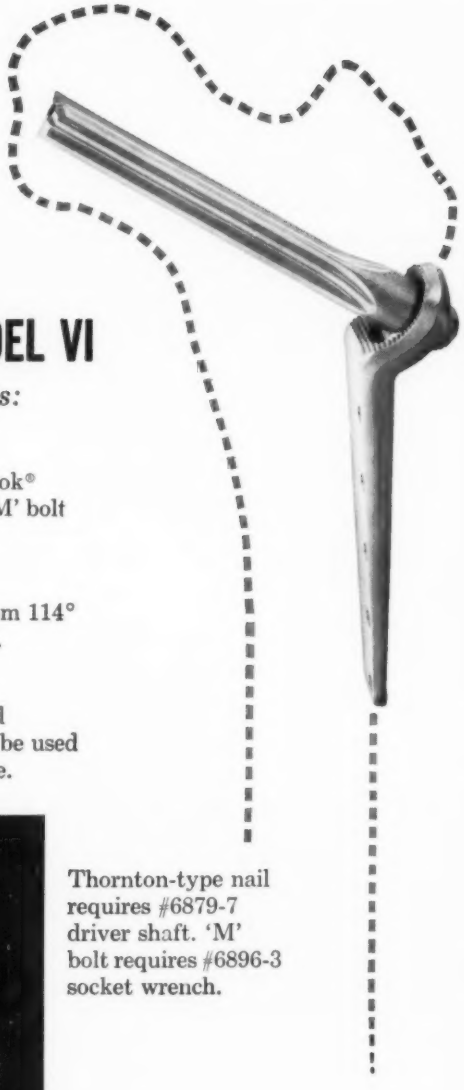
Complete information on dosage and administration is included in the package circular.

*Supply:* Vials of 5 cc. (25 mg. per cc.)

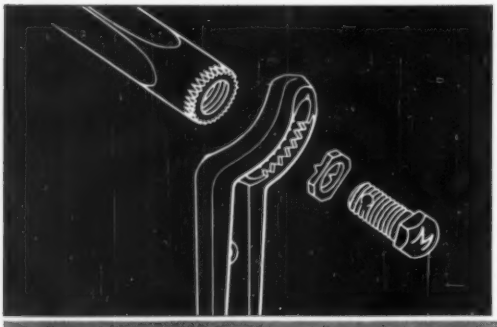
Lederle LEDERLE LABORATORIES, A Division of AMERICAN CYANAMID COMPANY, Pearl River, New York

# NEW and IMPROVED McLAUGHLIN APPLIANCE MODEL VI

*offers you these advantages:*



1. *Positive,* self-locking Nylok® device in strong 5/16″ 'M' bolt resists disengagement.
2. *Adjustable* angularity from 114° to 150° in 6° increments.
3. *Cannulated,* three-flanged Thornton-type nail, can be used with or without the plate.



Thornton-type nail requires #6879-7 driver shaft. 'M' bolt requires #6896-3 socket wrench.

VITALLIUM®

THE SYMBOL OF SURGICAL EXCELLENCE

AUSTENAL COMPANY *Surgical* PRODUCTS

DIVISION OF ROWE FOUND COMPANY

224 EAST 29TH STREET

NEW YORK 16, NEW YORK

# relieves painful muscle spasm, improves mobility, facilitates rehabilitation...

# PARAFLEX®

Chlorzoxazone*

PARAFLEX provides effective skeletal muscle relaxation for about 6 hours with a 1- to 2-tablet dose. It relieves pain and stiffness and improves function in a wide variety of orthopedic, arthritic, and rheumatic disorders. It may be used alone or with other agents indicated in the management of skeletal muscle spasm. It is especially valuable when used in conjunction with physiotherapy and other rehabilitative procedures. Side effects are rare, almost never require discontinuance of therapy.

*Dosage:* ADULTS—1 to 2 tablets three or four times a day.
CHILDREN—½ to 2 tablets three or four times a day, depending on age and weight.
*Supplied:* Tablets, scored, orange, bottles of 50. Each tablet contains PARAFLEX, 250 mg.

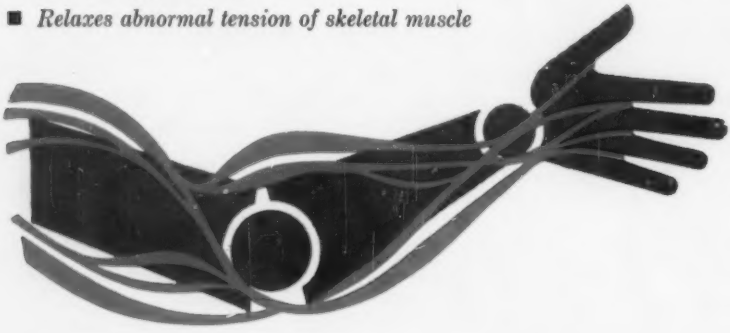
*U. S. Patent Pending 285A59

McNEIL

McNeil Laboratories, Inc.
Philadelphia 32, Pa.

now... a new way to relieve pain and stiffness in muscles and joints

- *Exhibits unusual analgesic properties, different from those of any other drug*
- *Specific and superior for relief of* SOMAtic *pain*
- *Modifies central perception of pain without abolishing natural defense reflexes*
- *Relaxes abnormal tension of skeletal muscle*



# SOMA™

N-isopropyl-2-methyl-2-propyl-1, 3-propanediol dicarbamate

In back pain, bursitis, sprains, strains, and bruises, whiplash and other traumatic injuries, inflammatory and degenerative muscle and joint complaints.

**RAPID ACTING.** Pain-relieving and relaxant effects start within 30 minutes and last for at least 6 hours.

**NOTABLY SAFE.** Toxicity is extremely low. No effects on liver, endocrine system, blood pressure, blood picture or urine have been reported. Some patients may become sleepy on higher than recommended dosage.

**EASY TO USE.** Usual adult dose is one 350 mg. tablet 3 times daily and at bedtime.

**SUPPLIED:** Bottles of 50 white sugar-coated 350 mg. tablets.

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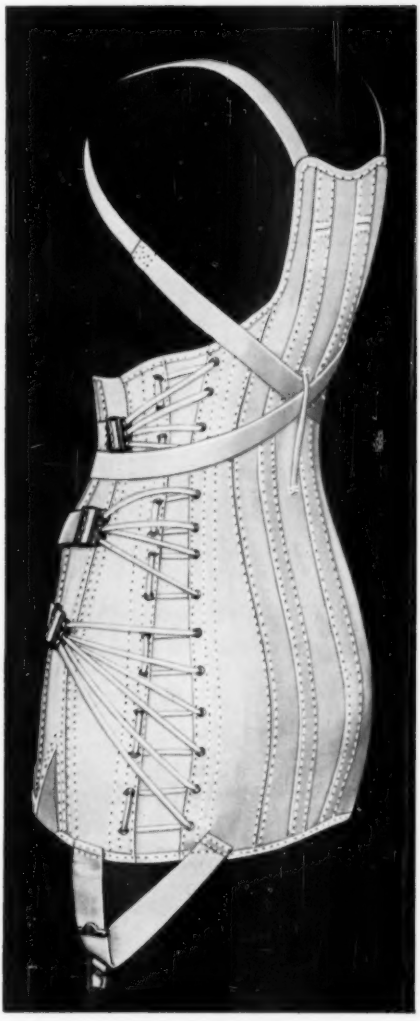

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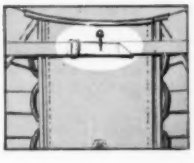

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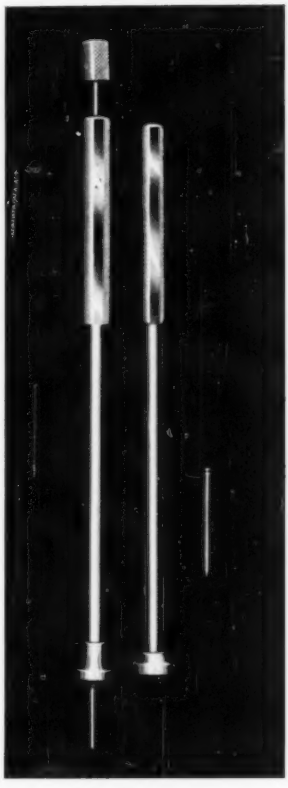

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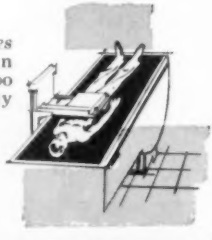

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# Alkaptonuria and Ochronosis

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This report is based on observations made of a group of twenty-two families who exhibited hereditary alkaptonuria. The disease was present in 119 individual members and of these, thirty-six had ochronotic arthropathy. This report will attempt to review the modern concept of the biochemical abnormality and the observed clinical findings in this rare disease. Although no direct correlation can be made between the biochemical abnormalities and the pathological findings in cartilage, the coincidence is of interest. The disease was first recognized in Slovakia in 1775 by Josephus Singer with the publication of his medical thesis "Morbum Nigrum Hippocratis". Its roentgenographic and medical aspects were more recently described by other authors.

## BIOCHEMISTRY

The basic biochemical abnormality is in the metabolism of tyrosine, which normally is transaminated to P-oxyphenylpyruvic acid, which then probably is further oxidized to 2,5 dioxyphenylpyruvic (homogentisic) acid. The evidence for this sequence is derived not only from alkaptonuric patients but also from experiments with liver slices from normal animals showing the usual anabolic pathway of tyrosine, and with scorbutic animals which demonstrate an abnormality in the breakdown of phenylalanine and tyrosine.

Normally, the benzene nucleus of homogentisic acid is split into an intramediary metabolite, a diketocarboxylic acid identified as fumarylacetic acid, which then is hydrolyzed enzymatically into fumaric and acetic acid. Two carbons from the benzene ring and two from the aliphatic chain are used to produce the acetic acid. The benzene ring is split between carbons one and two. When this hydrolysis is not complete homogentisic acid accumulates in the body and is discharged in the urine, often in amounts greater than two or three grams a day. In man, the metabolic defect causes alkaptonuria. The anabolism of tyrosine up to that point is normal, and other metabolites, for example, the hydroxyphenyl derivatives, do not occur in the urine.

Urine containing homogentisic acid in contact with atmospheric oxygen gradually becomes dark until it reaches a characteristic brownish black color. The process is strikingly speeded up when alkali is added. Alkaptonuric urine stains linen with grayish brown spots which after being washed with alkaline soap become darker and fixed. This symptom is an important aid in the detection of alkaptonuric disorders in the population. The laboratory demonstration of homogentisic acid in the urine is based on its reducing properties. Boiling of the urine with Fehling's solution yields a characteristic brownish black discoloration. A reliable method for detecting small amounts of homogentisic acid in urine is by

paper chromatography, and a more quantitative method, appropriate for follow-up of patients, is the iodometric test.

## CLINICAL FINDINGS

Alkaptonuria is generally considered a hereditary disease. In our series, every newly diagnosed patient afforded an opportunity for the discovery of new cases in his family. Since all of the families affected came from mountainous areas and from small villages in which endemic goiter has been shown to be prevalent, it may be of interest to point out the fact that tyrosine is the precursor not only of homogentisic acid but also of thyroxine. Another geographical fact, which may have some pertinence etiologically, is the prevalence of vitamin-C deficiency in the area. This is relevant because of the metabolic defect in tyrosine and phenylalanine breakdown (not, however, identical to the defect in alkaptonuria) which is demonstrable in scurvy.

FIG. 1

Photographs show (1) ochronotic pigmentation of the sclera—the black dotted pigmentation around the eyes is a typical finding, (2) a bluish tint of the thumb nail, the nail itself being hard and fragile, and (3) pigment collections in the auricle.

The clinical picture of alkaptonuria in man may be manifested by no other symptoms than the excretion of homogentisic acid. This single symptom may go on for decades before other symptoms supervene. The latter are due to the deposition of the homogentisic acid derivatives in many tissues, which then turn black or brown, and thus give rise to the term ochronosis, as described by Virchow. It is assumed that the ochronotic pigment is caused by oxidation and polymerization of homogentisic acid, probably by way of the enzyme tyrosinase. The ochronotic pigment is deposited in connective tissues in granules, mainly perivascularly in macrophages, but also extracellularly, and to a smaller degree in parenchymal cells. The sites of predilection for the pigment are numerous: pericardium, endocardium, vascular intima, bronchial cartilages, kidneys, adrenal glands, thyroid gland, testes, epididymides, and, to a lesser degree, spleen and pancreas. Although the clinical manifestations of these accumulations of pigment in internal organs are relatively small, the pigment may be widespread. A similar distribution of the same pigment is seen in chronic phenol poisoning—exogenous ochronosis.

The incidence of ochronosis according to age in our series was as follows: in the first decade of life, in twenty-one patients with alkaptonuria, ochronosis occurred in one patient who showed the ocular signs. The patients in the second decade showed no ochronosis, whereas those in the third, fourth, and fifth decades

showed increasing incidence of ochronosis, reaching 62.5 per cent in the fifth decade. A gradual decrease in incidence was noted in the sixth and seventh decades. In the eighth decade of life, the incidence was only 25 per cent. The earliest clinical manifestation was ocular pigmentation, and pigmentation of the auricles also preceded clinical arthropathy. However, of the clinical symptoms of alkaptonuric ochronosis, the most important were those in joints. These usually first appeared when the patients were between the ages of thirty and forty, the average age in this series being 34.6 years.

### OCHRONOTIC ARTHROPATHY

There were thirty-six patients—twenty-two male and fourteen female—who showed arthropathy. The average duration of symptoms was twelve years, the shortest being one year, and the longest thirty-four years. The patient showing earliest joint symptoms did so at the age of twenty-seven years. The patient showing joint symptoms the latest was fifty-one years old.

FIG. 2

FIG. 3

Fig. 2: In ochronotic arthropathy the spine is rigid and irregular, and the contours do not change in flexion. A characteristic finding is a slight kyphos at the thoracolumbar junction.

Fig. 3: Roentgenogram of the spine of a patient, thirty years old, showing narrowing of the discs, doubling of contours, and scoliotic deformity.

The first joint symptoms were in the spine. There was an indefinite sensation of stiffness in the lumbosacral region accompanied by some tenderness, but without systemic symptoms. The stiffness was accompanied by some pain, but never so intense as that which occurs in inflammatory conditions. Although progression of the disease with age was frequently noted, the pain did not necessarily increase proportionately to the advance of the pathological changes in the spine. In some cases ankylosis with complete rigidity was accompanied by only minimal pain. Some exceptions to this rule were noted. In six patients, the initial complaints were acute radicular pain similar to sciatica. In general, however, the arthropathy began insidiously without marked symptoms. In early cases, even when roentgenological findings were negative, the spine showed a gradual flattening of the physiological curves. As the disease developed further, there appeared a flattening of the lumbar lordosis accompanied by a fixed, rather sharp kyphosis in the lower thoracic or upper lumbar region, often involving only two or three

vertebrae. This was accompanied by decreased mobility of the spine. This degree of involvement was reached in the course of about three to five years after the first joint symptoms were experienced. With further evolution of the disease, a striking kyphosis was seen occasionally with its apex at the seventh or eighth thoracic vertebra. At this stage, which was reached six to eight years after the onset of joint symptoms, the spine was rigid. Eventually, both the lumbar and thoracic spine became rigid and ankylosed and showed certain irregularities, such as short segments of kyphosis, lordosis, and scoliosis. The muscles usually were

FIG. 4

FIG. 5

Fig. 4: Roentgenogram showing advanced spinal arthropathy with marked calcification of discs, and sclerosis, and osteolytic changes. The narrowing of the disc spaces is extensive and involves all of the discs shown.

Fig. 5: A lateral roentgenogram of the spine of a patient aged seventy-four (the oldest in the series). There is ankylosis of all of the vertebrae shown and marked osteoporosis. The discs are well calcified.

atrophic, but in some cases spasm was evident. The average height of our patients with ochronotic arthropathy was 158.5 centimeters in male patients and 151 centimeters in female patients, which, compared with the average height in the local population, was lower for men by 12.9 centimeters and for women by 6.1 centimeters. The patients' heights decreased during the course of the disease. In one patient the decrease over a period of twenty years was eight centimeters and occurred principally in the spine.

The roentgenographic findings initially were merely those of narrowing of the intervertebral spaces. These changes usually appeared first in the thoracolumbar region. Simultaneously, changes in the intervertebral discs in the form of doubling of their outlines appeared, and the bodies of the adjacent vertebrae seemed elongated. As the disease advanced, calcification of the discs often occurred, in contrast with the osteoporosis of the vertebral bodies. This osteoporosis

often was followed by secondary reactive hyperplasia, deformation of the bone, or bone destruction. In the fully developed cases, massive exostoses were found on the margins of vertebral bodies. Other areas showed pseudocysts of porotic foci. The changes in the discs were observed to advance to the point of disappearance of the discs and fusion of the adjacent vertebrae. In other patients destructive changes resembling neuropathic arthropathy occurred.

Ochronotic arthrosis of the spine could be differentiated from rheumatoid spondylitis both clinically and roentgenographically. Clinically, the almost painless onset and progress of this disease were in contrast with the pain found in

FIG. 6

FIG. 7

Fig. 6: Roentgenogram showing ochronotic pigmentation in the soft structures of the distal third of the leg and on the tibia itself.

Fig. 7: A roentgenogram of the shoulder showing characteristic findings. There is pseudocystic degeneration of the humeral head and of the acromion. There is narrowing and irregularity of the joint space. Flattening of the humeral head is noted, and pseudocystic degeneration of the bone at the origin of the long head of the biceps and of the deltoid is also noted.

rheumatoid spinal involvement. In ochronosis, the cervical spine usually showed roentgenographic changes of significance, whereas the clinical findings were still minimal. Only rarely was limitation of cervical motion seen to the extent that occurs in rheumatoid involvement of that area. However, there was considerable positional change of the cervical spine in ochronosis, with the head protruded forward and the cervical lordosis reduced. In the thorax the limitation or loss of respiratory excursion, frequently observed in rheumatoid spondylitis, was not present in the ochronotic patients.

Compared with osteo-arthritis, ochronotic arthropathy causes much more loss of function in the cervical spine. However, the most striking difference between these two diseases was found in the speed of progression. Ochronotic arthropathy develops faster and more extensively, causing earlier and more generalized rigidity of the thoracolumbar spine than is seen in osteo-arthritis.

FIG. 8

Pseudocyst formation at the insertion of the rectus femoris muscle.

FIG. 9

Advanced arthropathy of both hip joints is shown. There is narrowing of the joint space, osteophyte production, and flattening of the heads with sclerosis of the subchondral bone.

In this series the peripheral joints in ochronotic arthropathy were affected with the following frequency: knee joints, 64 per cent; shoulders, 42.3 per cent; and hips, 34.6 per cent. The small joints of the hands and feet, however, were spared.

The involvement of the knee joint was characterized by rapid progress and extensive deformity. Effusions occurred in 30.4 per cent of the patients, but there was no evidence of inflammation. Loss of knee motion, particularly in flexion, was observed, as well as progressive valgus deformities.

Limitation of motion of the shoulders usually developed about ten years after the beginning of the spinal involvement. The onset was insidious, and abduction and internal rotation were most severely affected, sometimes being restricted to one-fourth of the original range.

FIG. 10

Marked involvement in the knees of a patient, sixty-one years old, with hypertrophic changes in both patellae and marked sclerosis, particularly evident on the left.

Only advanced cases showed involvement of the hips: among the patients observed, eleven (six female) had ochronotic arthropathy of the hips; the involvement was rarely accompanied by pain, but rather was characterized by gradual loss of motion. Initially, there was loss of abduction and rotation but eventually, complete ankylosis and invalidism ensued. Involvement of the hip joints in ochronotic arthropathy was thus distinctly different from that in osteoarthritis.

On roentgenographic examination the peripheral joints showed increased density and disturbance in contour of the ends of the bones. The bony trabecular structure was irregular with spotty osteoporosis, pseudocysts, and spotty or segmental sclerosis. The progression of the findings often led to an uneven sclerosis, not unlike that seen in aseptic necrosis. The epiphyses of the humeri and femora in severe cases were flattened. Localized pseudocystic formations at the insertions of some tendons, for example, the long head of the biceps brachii, the supraspinatus, or the rectus femoris, were characteristic findings. The joint spaces were narrowed and asymmetrical, and marginal osteophytes were evident. Early changes in the knee joint, consisting of circumscribed sclerotic areas in the bone, were found in the majority of cases.

In our operative specimens, the pathological findings—similar to those of others—consisted mainly of the deposition of pigment in poorly vascularized areas, followed by degeneration and necrosis. Contrary to the experience of others, we did not find that the pigment was first deposited in intact or necrotic cartilage. We found the most massive and earliest deposition to occur in ligaments and periarticular tissues, especially at tendinous and capsular insertions. In the hip joint, a typical dark blue color was found at the origin of the rectus femoris and the acetabular attachment of the joint capsule. In one patient, the head of the femur showed absence of the usual smooth shiny cartilaginous surface, which was replaced by a dull gray tissue containing a dark continuous line, as might have been made by a charcoal pencil.

In a patient with knee involvement the operative findings included a dark blue discoloration of the subcutaneous and deep fascial tissues together with

massive impregnation by pigment of the patellar ligament and quadriceps tendon. In this patient the condyles of the femur were also pigmented dark blue, although the cartilage and bone were intact. The articular surface of the patella was roughened and showed a band of pigment 3.5 centimeters in width circumscribing it. Multiple foci of pigment were found in the loose connective tissue about the patella. The joint cartilage showed degeneration histologically, and in the pigmented areas only the remains of chondrocytes were seen.

### OCHRONOSIS OF OTHER TISSUES

Ocular ochronosis often precedes the appearance of articular symptoms. In one case, it was found in a patient eight years of age. There did not seem to be a direct relationship between the extent of ocular ochronosis and the arthropathy.

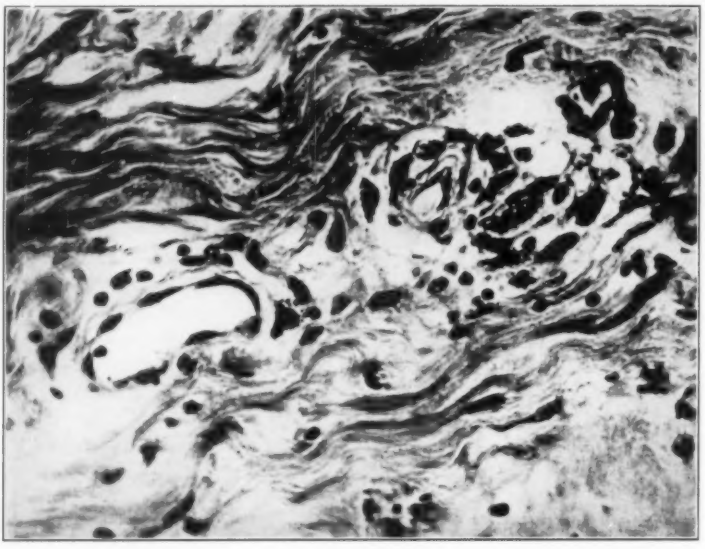

FIG. 11

Photomicrograph of tendon and adjacent capsular tissue showing pigment deposition in macrophages and in perivascular cells. There are also some tendon fragments which have pigment deposited in them.

The ocular changes did not include disturbance of vision or irritative phenomenon. Ochronosis was manifested by eye findings in 70.5 per cent of the patients. The findings were localized to the palpebral aperture. Homogeneous brownish blue spots were found in the sclerae above the insertion of the horizontal ocular muscles. Simultaneously, granules of pigment were seen in the bulbar conjunctivae and along the temporal and nasal margin of the corneae. Pigmentation of the corneae was a constant and pathognomonic finding in ochronosis.

In the ear, not only were pigment collections found in the auricle, but lesions involving the tympanic membrane, external auditory canal, and middle and inner ear were also seen. In seventeen patients with widespread ochronosis, twelve showed lesions of the ears, affecting the hearing. In one man, fifty-seven years old, the clinical picture was similar to otosclerosis. He had had tinnitus for twenty-eight years on the right and nineteen years on the left side with progressive loss of hearing to the point where he could only hear loud noises.

In the trachea and bronchi ochronosis, at times, manifested itself only by discoloration of the cartilage rings, without any symptoms. In some instances, however, symptoms were pronounced, consisting of inflammation and functional

disorders of respiration. Although ochronotic pigment may occur anywhere in the cartilaginous tissue of the respiratory system, there is a predilection for the larynx, with involvement of the arytenoidal tuberosities and the epiglottis. Similarly, in the bronchial tree pigmentation was most commonly seen in the carina and at the bifurcations of the bronchi. Cricoarytenoidal arthritis with medial fixation of the vocal cords was a severe complication. Laryngoscopy and bronchoscopy are required to demonstrate these changes.

The only visceral involvement manifested by the patients in this series which was worthy of mention was cholelithiasis (present in three female patients) and urolithiasis (present in two male patients). Whether these complications were caused by the essential disease is not known.

Characteristic changes in the skin and nails in advanced ochronosis were seen. A black dotted pigmentation around the eyes was typical. The nails were hard and fragile and had a bluish tint, with a brown stripe on the distal portions.

## TREATMENT

Since alkaptonuria is thought of as a metabolic disorder involving proteins, dietetic methods of treatment have occupied the foreground of general therapeutics in this disease. Starvation leads to a considerable decrease of the amount of homogentisic acid in the urine although it does not completely prevent alkaptonuria. Overloading of the patients with dietary protein distinctly increases the homogentisic acid in the urine. The results of therapeutic trials of restrictions of protein require long-term evaluation of many patients, which is not possible at this time.

Because of the influence of vitamin C on the metabolism of tyrosine and phenylalanine, treatment of ochronotic patients by administration of ascorbic acid has some rationale. A group of fifteen patients with well developed arthropathy given one to four grams of ascorbic acid daily and a standard diet of 2200 calories with 80 grams of protein showed the following. By the iodometric method the excreted homogentisic acid in twenty-four hours was not influenced even at the highest doses of ascorbic-acid administration. This treatment did not prevent the increased alkaptonuria caused by the administration of five grams of tyrosine daily. Whereas the intensity of the pigmentation was not influenced, the symptoms of the arthropathy were favorably affected. Although the alkaptonuria persisted, the dark stain of the urine was prevented by this treatment because the urine was kept acid and the ascorbic acid inhibited the oxidative changes. Theoretically, therefore, it seems possible that the ochronotic pigmentation may be prevented or diminished in these patients by such treatment.

The following drugs were administered to patients without significant effect: folic acid, vitamin $B_{12}$, liver extract, raw liver, cystine, and methionine. Clinical improvement after administration of ACTH was noted, but the excretion of homogentisic acid in the urine was not influenced by this drug.

The administration of 4-methyl-2 thiouracil given in doses of 300 to 500 milligrams daily resulted in a marked decrease of alkaptonuria and in a remission of clinical symptoms in two patients. Sudden withdrawal of the drug led to an acute relapse in one patient, whereas in two others, lasting benefit was achieved by maintenance doses in one and no significant effect was noted in the other.

The symptomatic treatment of ochronotic arthropathy included heat, massage, analgesic drugs, and physical therapy. Where there was severe joint deformity, arthroplasty, when indicated, was performed.

## BIBLIOGRAPHY

1. Abbott, L. D., Jr., and James, G. W., III: The Effect of Vitamin $B_{12}$ on Urinary Phenol Fractions in Pernicious Anemia. J. Lab. and Clin. Med., **35**: 35-42, 1950.
2. Abderhalden, Emil: Lehrbuch der physiologischen Chemie. Basel, Benno Schwabe, 1946.
3. Basser, A.: Alcaptonuria, with Report of an Additional Case. Med. J. Australia, **1**: 400-401, 1948.

4. Bauer, J., and Kienböck, R.: Zur Kenntnis der Knochen-und Gelenksveränderungen bei Alkaptonurie. Osteoarthrosis alcaptonurica (Ochronotica). Fortschr. Geb. Röntgenstrahlen, **40:** 32-42, 1929.
5. Baumann, E.: Ueber die Bestimmung der Homogentisinsäure im Alkaptonharn. Zeitschr. f. Physiol. Chem., **16:** 268-270, 1892.
6. Black, R. L.; Lowney, J. F.; and Duffy, P. M.: Alcaptonuria and Ochronosis. Report of Five Cases Occurring in an American Family. Arch. Int. Med., **93:** 75-86, 1954.
7. Blumenfield, Felix, and Jaffé, Rudolf: Pathologie der oberen Luft-und Speisewege. Leipsic, Carl Kabitzsch, 1931.
8. Boedeker, C.: Ueber das Alcapton; ein neuer Beitrag zur Frage: Welche Stoffe des Harnes Können Kupferreduction bewirken? Zeitschr. f. Rat. Med., **7:** 130-145, 1859.
9. Brunner, H.: Ueber die Veränderungen des Schläfenbeines bei der Ochronose. Monatsschr. f. Ohrenh., **63:** 997-1018, 1929.
10. Bürger, Max: Einführung in die pathologische Physiologie. Ed. 4. Leipsig, Georg Thieme, 1953.
11. Bürger, Max: Altern und Krankheit. Grundlagen einer biorheutischen Nosologie. Ed. 2. Leipsig, Georg Thieme, 1954.
12. Bürger, Max, and Schulze, W.: Osteoarthropathia und Osteoporosis alcaptonurica. Deutsche Zeitschr. f. Verdauungskr., **13:** 49-56, 1953.
13. Burckhardt, Hans: Arthritis deformans und chronische Gelenkkrankheiten. Stuttgart, Ferdinand Enke, 1932.
14. Butts, J. S.; Dunn, M. S.; and Hallman, L. F.: Studies in Amino Acid Metabolism. Metabolism of *Di*-Phenylalanine and *Di*-Tyrosine in a Normal Rat. J. Biol. Chem., **123:** 711-718, 1938.
15. Cain, L., and Berry, H. K.: *In* Individual Metabolic Patterns and Human Disease. An Exploratory Study Utilizing Predominantly Paper Chromatographic Methods, p. 77. University of Texas Publication No. 5109; Biochemical Institute Studies IV, Austin, University of Texas, 1951.
16. Cammarata, P. S., and Cohen, P. P.: Scope of Transamination Reaction in Animal Tissues. J. Biol. Chem., **187:** 439-452, 1950.
17. Červeňanský, Ján; Siťaj, Štefan; and Urbánek, Tibor: Ochronotic osteoarthrosis, p. 402. Sixième congrés de la Société Internationale de Chirurgie Orthopédique et de Traumatologie, Berne, Switzerland, August 30 to September 3, 1952.
18. Consden, R.; Glynn, L. E.; and Stanier, W. M.: A Chemical Examination of Connective Tissue in Rheumatic Fever. Biochem. J., **55:** 248-253, 1953.
19. Coodley, E. L., and Greco, A. J.: Clinical Aspects of Ochronosis. With Report of a Case. Am. J. Med., **8:** 816-822, 1950.
20. Cope, C. B., and Kassander, Paul: Cortisone in Ochronotic Arthritis. J. Am. Med. Assn., **150:** 997-999, 1952.
21. Crissey, R. E., and Day, A. J.: Ochronosis. A Case Report. J. Bone and Joint Surg., **32-A:** 688-690, July 1950.
22. Cserkesz, L. A.: Pathological Processes Induced by the Disorders of Protein and Vitamin Metabolism. Orv. Hetil., **92:** 1213-1222, 1951.
23. Díaz, C. J.; Mendoza, H. C.; and Rodríguez, J. S.: Alkapton, Aceton und Kohlehydratmangel. Klin. Wochnschr., **18:** 965-966, 1939.
24. Diseases of Metabolism. Detailed Methods of Diagnosis and Treatment. Edited by Garfield G. Duncan. Philadelphia, W. B. Saunders Co., 1942.
25. Djujel, G.: Bielki i aminokysloti v pitanni čeloveka i životnich. Moskva, Izdatel'stvo Inostrannoj Literatury, 1952.
26. Duchoň, J.; Jirka, M.; Krejčí, E., and Richter, A. F.: Studies on the Metabolism of Homogentisic Acid. Čas. Lék. Českych, **93:** 591-602, 1954.
27. Ehrlich, L.: Ein Fall von ochronotischer Alkaptonurie mit erheblichen Skelettveränderungen. Röntgenpraxis, **4:** 865-870, 1932.
28. Eisenberg, Harry: Alkaptonuria, Ochronosis, Arthritis and Ruptured Intervertebral Disk. Complicated by Homologous Serum Reaction. Arch. Int. Med., **86:** 79-86, 1950.
29. Embden, H.: Beiträge zur Kenntniss der Alkaptonurie. Zeitschr. f. Physiol. Chem., **17:** 182-192, 1892.
30. Falta, W., and Langstein, M.: Die Entstehung von Homogentisinsäure aus Phenylalanin. Zeitschr. f. Physiol. Chem., **37:** 513-517, 1903.
31. Felix, K.; Leonhardi, G.; and Glasenapp, I. V.: Über Tyrosinosis. Zeitschr. f. Physiol. Chem., **287:** 141-147, 1951.
32. Ferrero, C.: Réaction de Millon positive dans l'insuffisance surrénale. Schweizerische Med. Wochnschr., **80:** 492-498, 1950.
33. Ferrero, C., and Doret, J. P.: Test à la tyrosine dans la polyarthrite chronique évolutive. Helvetica Med. Acta, **17:** 557-560, 1950.
34. Fishberg, E. H.: Excretion of Benzoquinoneacetic Acid in Hypovitaminosis C. J. Biol. Chem., **172:** 155-163, 1948.
35. Flaschenträger, B.; Halawani, A.; and Nabeh, I.: Alkaptonurie und Vitamin $B_{12}$. Klin. Wochnschr., **32:** 131-133, 1954.
36. Fölling, A.; Closs, K.; and Gamnes, T.: Vorläufige Schlussfolgerungen aus Belastungsversuchen mit Phenylalanin an Menschen und Tieren. Zeitschr. f. Physiol. Chem., **256:** 1-14, 1938.
37. Forestier, J.; Jacqueline, F.; and Rotes-Querol, J.: La spondylarthrite ankylosante. Clinique, radiologie, anatomie pathologique, traitement. Paris, Masson et Cie., 1951.
38. Fürst, E.: Aural Manifestations in Alkaptonuria and Ochronosis. Československá Otolar., **3:** 5-9, 1954.

39. Gabuzda, G. J., Jr..; Eckhardt, R. D.; and Davidson, C. S.: Urinary Excretion of Amino Acids in Patients with Cirrhosis of the Liver and in Normal Adults. J. Clin. Invest., **31:** 1015-1022, 1952.
40. Galdston, Morton; Steele, J. M.; and Dobriner, Konrad: Alcaptonuria and Ochronosis. With a Report of Three Patients and Metabolic Studies in Two. Am. J. Med., **13:** 432-452, 1952.
41. Garrod, A. E.: Inborn Errors of Metabolism. Ed. 2. London, Oxford University Press, 1923.
42. Gould, J. N., and Thomas, T. G.: Diagnosis of Alkaptonuria. British Med. J., **1:** 788, 1943.
43. Govan, C. D., Jr., and Gordon, H. H.: The Effect of Pteroylglutamic Acid on the Aromatic Amino Acid Metabolism of Premature Infants. Science, **109:** 332-333, 1949.
44. Gros, Helmut, and Kirnberger, Ernst-Josef: Spontanausscheidung von p-Oxyphenylbrenztraubensäure im Harn. Klin. Wochnschr., **32:** 115-119, 1954.
45. Gross, J., and LeBlond, C. P.: The Presence of Free Iodinated Compounds in Thyroid and Their Passage into Circulation. Endocrinology, **48:** 714-725, 1951.
46. Gross, O., and Allard, E.: Untersuchungen über Alkaptonurie. Zeitschr. f. Klin. Med., **64:** 359-369, 1907.
47. Hall, W. K.; Hawkins, K. R.; and Child, G. P.: Inheritance of Alkaptonuria in Large American Families. J. Hered., **41:** 23-25, 1950.
48. Hench, P. S.: Rheumatism and Arthritis. Review of American and English Literature of Recent Years (Ninth Rheumatism Review). Part II. Ann. Int. Med., **28:** 309-451, 1948.
49. Hertzberg, J.: On Osteoarthrosis Alkaptonurica (Ochronotica) with Description of One Case. Acta Radiol., **26:** 484-490, 1945.
50. Hirsch, C.: Contribution to the Pathogenesis of Chondromalacia of the Patella. Physical, Histologic and Chemical Study. Acta Chir. Scandinavica, **90:** Supplementum 83, 1944.
51. van der Hoeve, J.: Presentation of Cases: A Case of Ochronosis with Typical Dark Patch in the Sclera of Both Eyes. Ophthalmologica, **115:** 378, 1948.
52. Hogben, L.; Worral, R. L.; and Zieve, I.: The Genetic Basis of Alkaptonuria. Proc. Roy. Soc. Edinburgh, **52:** 264, 1932.
53. Hürthle, R.: Zur Frage des Verhaltens der Homogentisinsäure im Serum des Normalen und des Alkaptonurikers. Zeitschr. f. Klin. Med., **119:** 15-18, 1932.
54. Hürthle, R.: Weitere Untersuchungen über relative Alkaptonurie: zur Frage ihrer Ursache. Zeitschr. f. Klin. Med., **119:** 19-28, 1932.
55. Hultén, O., and Gellerstedt, N.: Über Abnutzungsprodukte in Gelenken und ihre Resorption unter dem Bilde einer Synovitis detritica. Acta Chir. Scandinavica, **84:** 1-29, 1941.
56. Janeček, M.: Ochronotic (Alkaptonurie) osteoarthrosis. Lék. Listy, **2:** 536-540, 1947.
57. Jervis, G. A.: Phenylpyruvic Oligophrenia Deficiency of Phenylalanine-Oxidizing System. Proc. Soc. Exper. Biol. and Med., **82:** 514-515, 1953.
58. Jones, J. D.; Smith, B. S. W.; and Evans, W. C.: Homogentisic Acid an Intermediate in the Metabolism of Tyrosine by the Aromatic Ring-Splitting Micro-organisms. Biochem. J., **51:** xi-xii, 1952.
59. Katsch, G.: Genuine und relative Alkaptonurie. Zeitschr. f. Klin. Med., **119:** 1-9, 1932.
60. Katsch, G., und Hürthle, R.: Über chemisches und biologisches Verhalten synthetischer Homogentisinsäure. Zeitschr. f. Klin. Med., **119:** 10-13, 1932.
61. Kellgren, J. H.: Some Concepts of Rheumatic Disease (Goulstonian Lecture). British Med. J., **1:** 181-187, 1952.
62. Kirberger, E., and Bücher, T.: Ausscheidung von p-Oxyphenylessigsäure nach Belastung mit p-Oxyphenylbrenztraubensäure beim Kaninchen. Biochim. Biophys. Acta, **8:** 294-301, 1952.
63. Klein, O., and Bloch, K.: Beseitigung der Alkaptonurie durch parenterale Zufuhr von Leberextrakten. Klin. Wochnschr., **15:** 1684, 1936.
64. Knox, W. E., and LeMay-Knox, M.: The Oxidation of l-Tyrosine to Acetoacetate through p-Hydroxyphenylpyruvate and Homogentisic Acid. Biochem. J., **49:** 686-693, 1951.
65. Kolaczek, H.: Ueber Ochronose. Beitr. z. Klin. Chir., **71:** 254-316, 1910.
66. Kollár, K.; Červeňanský, Ján; and Surovecký, J.: Problem of Ochronosis. Lék. Obzor., **1:** 596-606, 1952.
67. Korec, Rudolf: K problému alkaptonurie. Bratislavské Lék. Listy, **27:** 170-175, 1947.
68. Lang, F. J.: Pathologie der chronischen Gelenkleiden. Dresden, Theodor Steinkopff, 1943.
69. Lang, Konrad: Der intermediäre Stoffwechsel. Berlin, Julius Springer, 1952.
70. Lanyar, Franz: Alkaptonurie und Schwangerschaft. Zeitschr. f. Physiol. Chem., **273:** 283-284, 1942.
71. Lanyar, Franz: Über den Abbau der d-und l-Forum des Phenylalanins und der d, l-und l-Form des Tyrosins durch den Alkaptonuriker. Zeitschr. f. Physiol. Chem., **275:** 217-224, 1942.
72. Lanyar, Franz, and Lieb, Hans: Alkaptonurie und Kohlehydratentziehung. Zeitschr. f. Physiol. Chem., **186:** 119-123, 1930.
73. Lenoch, F.: Clinical Signs of Spondylarthritis Ankylopoietica. Časop. Lék. Českých, **80:** 420-427, 1941.
74. Lenoch, F.; Trulař, P.; Poláková, Z.; Kučerova, K.; Jarolímek, J.; Popelka, S.; Procházka, J.; Kvaček, J.; Nechvátalová, L; Paurová, V.; Malaska, V.; and Zámostná, M.: Complex Spa Treatment of Ankylosing Spondylitis. Acta Chir. Orthop. et Traumatol. Čechoslovaca, **19:** 7-19, 1952.
75. Lerner, A. B.: Metabolism of Phenylalanine and Tyrosine. Advances Enzymol., **14:** 73-128, 1953.

76. Leslie, Alan: Alkaptonuria with Hyperuricemia. Arch. Int. Med., **71:** 68-77, 1943.
77. Levine, S. Z.; Marples, Eleanor; and Gordon, H. H.: Defect in Metabolism of Aromatic Amino Acids in Premature Infants: Role of Vitamin C. Science, **90:** 620-621, 1939.
78. Levine, S. Z.; Dann, Margaret; and Marples, Eleanor: A Defect in the Metabolism of Tyrosine and Phenylalanine in Premature Infants. III. Demonstration of the Irreversible Conversion of Phenylalanine to Tyrosine in the Human Organism. J. Clin. Invest., **22:** 551-562, 1943.
79. Levine, S. Z.; Barnett, H. L.; Bierman, C. W.; and McNamara, Helen: Effect of ACTH and Some Adrenocortical Steroids on the Metabolism of Tyrosine and Phenylalanine in Premature Infants. Science, **113:** 311-312, 1951.
80. Lieb, H., and Lanyar, Franz: Über die jodometrische Bestimmung der Homogentisinsäure im Harn. Zeitschr. f. Physiol. Chem., **181:** 199-207, 1929.
81. Lichtenstein, Louis, and Kaplan, Leo: Hereditary Ochronosis. Pathologic Changes Observed in Two Necropsied Cases. Am. J. Pathol., **30:** 99-126, 1954.
82. Lichtwitz, L.: *In* Kurzes Handbuch der Ophthalmologie. Vol. 7, pp. 29-30. Edited by F. Schieck and A. Brückner. Berlin, Julius Springer, 1932.
83. Martin, E.; Milhaud, G.; and Courvoisier, B.: Étude de l'alcaptonurie. Schweizerische Med. Wochnschr., **80:** 981-985, 1950.
84. Martin, E.; Milhaud, G.; Courvoisier, B.; and Lapiné, A.: Étude de deux cas d'alcaptonurie. Bull. et Mém. Soc. Méd. Hôp. de Paris, **66:** 1050-1054, 1913.
85. Matějka, J.: O alkaptonurie. Časop. Lék. Českých, **52:** 1497-1504, 1913.
86. Matthews, B. F.: Collagen Chondroitin Sulphate Ratio of Human Articular Cartilage Related to Function. British Med. J., **2:** 1295, 1952.
87. Mauser, C. L.: Alkaptonuria. J. Am. Med. Assn., **146:** 815-816, 1951.
88. Medes, G.: New Error of Tyrosine Metabolism: Tyrosinosis. Intermediary Metabolism of Tyrosine and Phenylalanine. Biochem. J., **26:** 917-940, 1932.
89. Metz, Ernst: An Iodometric Method for Determining Homogentisic Acid in Urine. Biochem. Zeitschr., **190:** 261-264, 1927.
90. Mitchell, P. H.: A Textbook of Biochemistry. New York, McGraw-Hill Book Co., 1950.
91. Mittelbach, Franz: Ein Beitrag zur Kenntniss der Alkaptonurie. Deutsches Arch. f. Klin. Med., **71:** 50-72, 1901.
92. Morris, J. E.; Harpur, E. R.; and Goldbloom, A.: Metabolism of l-Tyrosine in Infantile Scurvy. J. Clin. Invest., **29:** 325-335, 1950.
93. Mosonyi, Ladislas: A propos de l'acaptonurie et de son traitement. Presse Méd., **47:** 708-709, 1939.
94. Moss, A. R., and Schoenheimer, R. J.: Conversion of Phenylalanine to Tyrosine in Normal Rats. J. Biol. Chem., **135:** 415-429, 1940.
95. Müller, Friedrich: *In* Festschrift zum 65. Geburtstag von Gerhardt Katsch. Edited by Friedrich Müller. Stuttgart, Georg Thieme, 1952.
96. Neubauer, O.: Ueber den Abbau der Aminosäuren im gesunden und kranken Organismus. Deutsches Arch. f. Klin. Med., **95:** 211-256, 1909.
97. Neuberger, A.: Studies on Alcaptonuria. I. The Estimation of Homogentisic Acid. Biochem. J., **41:** 431-438, 1947.
98. Neuberger, A.; Rimington, C.; and Wilson, J. M. G.: Studies on Alcaptonuria. II. Investigations on a Case of Human Alcaptonuria. Biochem. J., **41:** 438-449, 1947.
99. Neuberger, A., and Webster, T. A.: Studies on Alcaptonuria. III. Experimental Alcaptonuria in Rats. Biochem. J., **41:** 449-457, 1947.
100. Nitkitin, T. R., and Pribylov, K. N.: Medicinskij kontrol za fisičeskim vospitaniem i lečebnaja fizičeskaja kultura. Moskva, Medgiz, 1951.
101. Oppenheimer, B. S., and Kline, B. S.: Ochronosis; with a Study of an Additional Case. Arch. Int. Med., **29:** 732-747, 1922.
102. Paschkis, K. E.; Cantarow, A.; Hart, W. M.; and Rakoff, A. E.: Inhibitory Action of Thiouracil, Thiocarbamide and Other Compounds on Melanin Formation by Tyrosinase. Proc. Soc. Exper. Biol. and Med., **57:** 37-39, 1944.
103. Pelnář, J., and Lenoch, F.: Pathologie a therapie nemocí vnitřních III. Praha, SZN, 1953.
104. Pomeranz, M. D.; Friedman, L. J.; and Tunick, I. S.: Roentgen Findings in Alkaptonuric Ochronosis. Radiology, **37:** 295-302, 1941.
105. Postranécký, O.: Fysiologie a pathologie přeměny látek. Praha, Svoboda, 1949.
106. Procházka, J., and Hnévkovský, O.: Degenerative Articular Changes in Alkaptonuria and Their Role in the Problem of Etiology of Arthroses. Acta Orthop. et Traumatol. Čechoslovaca, **20:** 53-49, 1953.
107. Raper, H. S.: Tyrosinase. Ergebn. Enzymforsch., **1:** 270-279, 1932.
108. Ravdin, R. G., and Crandall, D. I.: The Enzymatic Conversion of Homogentisic Acid to 4-Fumarylacetoacetic Acid. J. Biol. Chem., **189:** 137-149, 1951.
109. Rienits, K. G.: Metabolism of *l*-Ascorbic Acid and l-Tyrosine in Guinea Pig Liver. J. Biol. Chem., **182:** 11-16, 1950.
110. Rodney, Gertrude; Swendseid, M. E.; and Swanson, A. L.: The Rôle of Pteroylglutamic Acid in Tyrosine Oxidation by Rat Liver Tissue. J. Biol. Chem., **179:** 19-24, 1949.
111. Rogers, W. F., and Gardner, F. H.: Tyrosine Metabolism in Human Scurvy. J. Lab. and Clin. Med., **39:** 1491-1501, 1949.
112. Sallmann, Ludwig: Über die Augenpigmentierung bei endogener Ochronose. Zeitschr. f. Augenheil., **60:** 164-171, 1926.
113. Salmon, R. J., and May, C. D.: The Effect of Folinic Acid (Citrovorum Factor) and of Cortisone on the Metabolism of Tyrosine in a Scorbutic Monkey. Arch. Biol. Chem., **32:** 220-221, 1951.

114. Salmon, R. J., and May, C. D.: Further Studies on the Metabolism of l-Tyrosine in Scorbutic Monkeys. The Effect of Folinic Acid, Cortisone, Adrenalectomy, and Sulfhydryl Groups on Urinary Excretion of p-Hydroxy-phenyl Compounds. J. Lab. and Clin. Med., **41:** 376-392, 1953.
115. Salvi, G. L.: Alkaptonuric ocular ochronosis. Boll. d'Oculist., **29:** 164-172, 1950.
116. Schepartz, Bernard: Transamination as a Step in Tyrosine Metabolism. J. Biol. Chem., **193:** 293-298, 1951.
117. Schepartz, Bernard, and Nadel, E. M.: Effect of Ascorbic Acid; Folic Acid and Vitamin $B_{12}$ upon Tyrosine Oxidation in Acetone Powder Preparations of Guinea Pig Liver. Fed. Proc., **11:** 425, 1952.
118. Schwartz, M. A., and Williams, J. N., Jr.: Further Studies on Folic Acid-Ascorbic Acid Interrelationships in the Rat. J. Biol. Chem., **197:** 481-484, 1952.
119. Sealock, R. R.; Galdston, Morton; and Steele, J. M.: Administration of Ascorbic Acid to Alkaptonuric Patient. Proc. Soc. Exper. Biol. and Med., **44:** 580-583, 1940.
120. Sealock, R. R., and Goodland, R. L.: Ascorbic Acid, Coenzyme in Tyrosine Oxidation. Science, **114:** 645-646, 1951.
121. Sealock, R. R.; Perkinson, J. D., Jr.; and Basinski, D. H.: Further Analysis of the Role of Ascorbic Acid in Phenylalanine and Tyrosine Metabolism. J. Biol. Chem., **140:** 153-160, 1941.
122. Sealock, R. R., and Silberstein, H. E.: Control of Experimental Alcaptonuria by Means of Vitamin C. Science, **90:** 517, 1939.
123. Sigg, B.: Über Alkaptonurie. Ann. Paediat., **175:** 157-168, 1950.
124. Sitaj, Štefan: Arthropatia alkaptonurica. Bratislavské Lék. Listy, **27:** 1-9, 1947.
125. Sitaj, Štefan; Urbánek, Tibor; and Weiszer, L.: Experience with Vitamin C and 4-methyl-2-thiouracil in Ochronotic Arthropathy. Bratislavské Lék. Listy, **33:** 179-187, 1953.
126. Sitaj, Štefan; Červeňanský, Ján; Urbanek, Tibor, a spolupracovníci J. Stanek; Hladký, R.; Fürst, E.; Adda, V.; and Niepel, G.: Alkaptonúria a Ochronóza. Bratislava, Slovenská Akadémia Vied, 1956.
127. Skinsnes, O. K.: Generalized Ochronosis. Report of an Instance in Which It Was Misdiagnosed as Melansarcoma, with Resultant Enucleation of Eye. Arch. Pathol., **45:** 552-558, 1948.
128. Smith, J. W.: Ochronosis of Sclera and Cornea Complicating Alkaptonuria. Review of Literature and Report of Four Cases. J. Am. Med. Assn., **120:** 1282-1288, 1942.
129. Söderbergh, Gotthard: Zur Klinik der Alkaptonurie, insbesondere über die Wassermann'sche Reaktion und Ostitis deformans alcaptonurica. Nordisk Med. Arkiv, Afd., **11,** Nr. 19, 48: 1-130, 1915.
130. Steffens, C. A.: *In* Rheumatic Diseases. Proceedings of the Seventh International Congress on Rheumatic Diseases. Edited by Charles H. Slocumb. Philadelphia, W. B. Saunders Co., 1952.
131. Sternberg, M.: Über eine eigenartige periarthritische Erkrankung "Sclerodesmia periarticularis pigmentosa". Med. Klin., **30:** 1490-1491, 1934.
132. Suda, M.; Takeda, Y.; Sujishi, K.; and Tanaka, T.: Metabolism of Tyrosine. Relation Between Homogentisicase, Ferrous Ion and l-Ascorbic Acid in Experimental Alcaptonuria of Guinea Pig. J. Biochem., **38:** 297-302, 1951.
133. Swendseid, M. E.; Wandruff, B.; and Bethell, F. H.: Urinary Phenols in Pernicious Anemia. J. Lab. and Clin. Med., **32:** 1242-1247, 1947.
134. Šrámek, Raimund: Případ alkaptonurie. Demonstra. Čas. Lék. Českych, **76:** 351, 1937.
135. Švejda, Jaroslav: Příspěk k otázce ochronozy. Čas. Lék. Českych, **84:** 1036-1038, 1945.
136. Thannhauser, S. J.: Lehrbuch des Stoffwechsels und der Stoffwechselkrankheiten. München, Bergmann, 1929.
137. Udenfriend, Sidney, and Cooper, J. R.: The Enzymatic Conversion of Phenylalanine to Tyrosine. J. Biol. Chem., **194:** 503-511, 1952.
138. Uebermuth, H.: Zur Kenntnis der Gelenkveränderungen bei endogener Ochronose (Chondrosis dissecans ochronotica). Virchows Arch. f. Pathol. Anat., **270:** 276-308, 1928.
139. Umber, Friedrich: Ernährung und Stoffwechselkrankheiten. Ed. 3. Berlin, Urban und Schwarzenberg, 1925.
140. Urbánek, Tibor, and Sitaj, Štefan: Simultaneous Occurrence of Alkaptonuria, Ochronotic Arthropathy and Bechterew's Disease. Fysiat Věst., **33:** 85-91, 1955.
141. Utkin, L. M.: Homogentisic Acid in the Fungous Metabolism. Biochimija Moskva, **15:** 330-333, 1950.
142. Virchow, Rud.: Ein Fall von allgemeiner Ochronose der Knorpel and knorpelähnlichen Theile. Virchows Arch. f. Pathol. Anat., **37:** 212-219, 1866.
143. Weinhouse, Sidney, and Millington, R. H.: Ketone Body Formation from Tyrosine. J. Biol. Chem., **175:** 995-996, 1948.
144. White, A. G.: Effect of Tyrosine, Tryptophane, and Thiouracil on Melanuria. J. Lab. and Clin. Med., **32:** 1254-1259, 1947.
145. White, A. G.; Parker, J. G.; and Block, Frank: Studies on Human Alcaptonuria. Effect of Thiouracil Para-Aminobenzoic Acid and Di-Iodotyrosine on Excretion of Homogentisic Acid. J. Clin. Invest., **28:** 140-143, 1949.
146. Winnick, Theodore; Friedberg, Felix; and Greenberg, D. M.: Studies in Protein Metabolism with Compounds Labeled with Radioactive Carbon. I. Metabolism of dl-Tyrosine in the Normal and Tumor-Bearing Rat. J. Biol. Chem., **173:** 189-197, 1948.
147. Woodruff, C. W., and Darby, W. J.: An *in vivo* Effect of Pteroylglutamic Acid upon Tyrosine Metabolism in the Scorbutic Guinea Pig. J. Biol. Chem., **172:** 851-852, 1948.
148. Woodruff, C. W.; Cherrington, M. E.; Stockwell, A. K.; and Darby, W. J.: The Effect of Pteroylglutamic Acid and Related Compounds upon Tyrosine Metabolism in the Scorbutic Guinea Pig. J. Biol. Chem., **178:** 861-868, 1949.

149. Woolf, L. I.; and Edmunds, M. E.: The Metabolism of Tyrosine and Phenylalanine in Premature Infants: the Effect of Large Doses. Biochem. J., 47: 630-637, 1950.
150. Woolley, P. B.: Exogenous Ochronosis. British Med. J., 2: 760-761, 1952.
151. Zahradníček, Jan: Deformační arthrosa. Praha, St. Zdrav. Nakl., 1953.
152. Zbarskii, I. B.; Ivanov, I. I.; and Mardašev, S. R.: Biologičeskaja Chimija. Moskva, Medgiz, 1951.

# Factors Preventing Downward Dislocation of the Adducted Shoulder Joint

## An Electromyographic and Morphological Study*

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The part played by various muscles during movements of the shoulder joint has been the subject of investigation and argument for more than a century. Even though most of the important questions on movements in the shoulder area were finally and authoritatively answered by Inman, Abbott, and Saunders in 1944, little reliable information had been available regarding the role of such muscles in maintaining joint stability. In particular, the mechanism preventing downward dislocation or subluxation of the shoulder joint has not been adequately explained—indeed, it has been largely ignored. Cotton in 1921 and Fairbank in 1948, considering the matter in connection with fractures of the humeral neck, both assigned the greatest importance to the vertically running scapulohumeral muscles, for example, deltoid and biceps. During some incidental studies of the region, we were surprised to find the exact opposite. Therefore, to clarify the part played by the muscles and the capsule of the joint in preventing downward dislocation of the vertical or adducted humerus the following two types of systematic investigation were performed:

1. An electromyographic study of the deltoid, supraspinatus, infraspinatus, biceps, and triceps of a series of young men using multiple concentric-needle electrodes;

2. A study of gross dissections of the shoulder joint.

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## MATERIAL AND METHODS

### 1. *Electromyography*

The subjects for electromyography were twenty-two young normal male volunteers. Alternate left and right sides were examined, disregarding whether the subjects were left-handed or right-handed. In eight subjects the three parts of the deltoid (anterior, middle, and posterior) and the supraspinatus were studied simultaneously (in one of these subjects, the biceps was also studied simultaneously). In eleven subjects, the supraspinatus and infraspinatus were studied simultaneously. In five subjects, the biceps was studied; in four of these the long head of the triceps was studied simultaneously.

The subjects were all examined in a comfortable, seated position. At each site chosen for insertion of an electrode a small skin wheal was raised with 1 per cent procaine and through this the electrode was thrust into the muscle. In the case of the deltoid, the needle in the anterior fibers was two inches below the lateral end of the clavicle; that in the middle fibers was two inches below the lateral border of the acromion; and that in the posterior fibers was about three inches below the spine of the scapula. The electrodes in the supraspinatus and the infraspinatus were placed in or near the middle of their bellies. The electrodes in the biceps were placed in the middle of the muscle whereas those in the triceps were placed in the middle of its long hand. In no instance was pain experienced by the subjects during these experiments.

The electrodes used were concentric-needle electrodes of a type described previously [1]. The electromyograph is a special six-channel apparatus consisting of six separate amplifiers and cathode-ray oscilloscopes whose faces can be photographed simultaneously on the same strip of continuous-moving thirty-five millimeter linagraph film [2]. Even the slightest electromyographic activity can be accurately recorded.

Although considerable tests other than those to be described were performed, (for example, various movements of the shoulder joint) only those concerning the present inquiry will be considered here:

A. *Static unloaded hanging arm:* The subject was seated upright with his arm hanging in the relaxed neutral position (the forearm midway between pronation and supination).

B. *Static loaded hanging arm:* Two types of load were added to the subject's arm. The first of these was a load of sixteen pounds (lead weights held in the hand to the limit of individual endurance which proved to be a variable factor). The other load, less precise but more effective, was a sudden heavy sustained downward pull by one of the observers on the subject's hanging arm. This, of course, was both a dynamic and a static loading of the arm. In five persons a longitudinal pull was applied to the arm which had been abducted to the horizontal plane and completely supported by another observer so that no abduction activity was required of the subject's muscles.

### 2. *Gross Dissections*

In a series of seven shoulder joints of routinely embalmed dissecting-room subjects a careful dissection was made. The rotator cuff muscles were raised from their origins on the scapula and stripped away from the bone and the joint capsule. In some of these shoulders the tendons could be stripped off the capsule with ease; in others, sharp dissection was required to separate them from the capsule.

## RESULTS

### 1. *Electromyography*

A. *Static unloaded hanging arm:* In this position electromyographic activity in all three parts of the deltoid ceased almost immediately. Meanwhile, the activity in the supraspinatus fell off and eventually reached nil. However, the length of

time between electrode insertion and nil activity of the supraspinatus varied from immediately in several subjects to one hour in one subject. The infraspinatus, like the deltoid, relaxed completely almost immediately in all subjects while the biceps and the triceps showed no activity (either intermittent or continuous).

B. *Static loaded hanging arm:* The limit of endurance in the subjects holding the sixteen-pound load varied from three to thirteen minutes. (Weight-holding was discontinued in each person because of the fatigue experienced in the forearm and hand in maintaining the unchanging and, therefore, uncomfortable position.) With this load, the supraspinatus varied from subject to subject, ranging from no electromyographic activity to marked activity, being quite active in general. The posterior fibers of the deltoid showed a range from no activity to only moderate activity. The anterior and middle fibers, in contrast, showed no activity in almost all the subjects and in the two subjects in whom there was some activity it was quite slight. Moreover, when activity was present, there was some slight rise and fall from minute to minute.

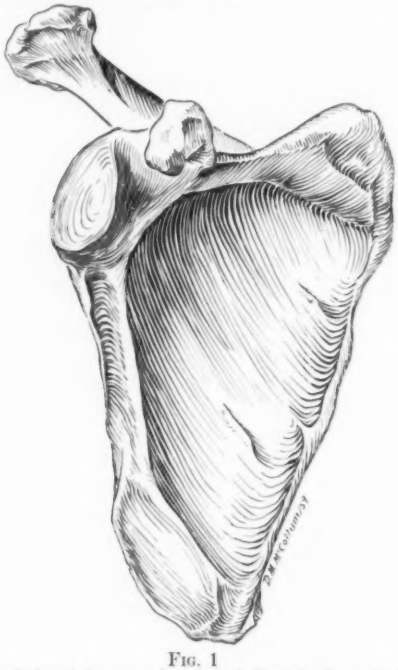

FIG. 1

Correct orientation of the right scapula viewed directly from in front at eye level.

During the sudden but sustained heavy pull downward, the surprising result was that there was no appreciable increase in activity of the anterior and middle fibers of the deltoid. However, the activity in the supraspinatus and the posterior fibers of the deltoid increased appreciably in all but one subject during the downward pull applied to the arm. In the case of the horizontal pull, the results were similar; again the activity of the anterior and middle fibers of the deltoid muscle was not increased whereas the activity in the posterior deltoid and supraspinatus was increased.

There was no activity in the biceps and triceps muscles even when the arm was pulled vigorously downward.

2. *Gross Dissections*

Once the muscles and tendons were dissected from the capsule of the shoulder joint it was apparent that the capsule was quite lax except when the joint was

of the humerus could be pulled away from the glenoid fossa for a distance of 0.5 to 1.0 centimeter only if the humerus was abducted. When the shoulder was held in marked abduction or marked adduction. In all seven specimens the head was adducted with the humerus vertical and the scapula held in the anatomical position, the humeral head could not be moved downward at all. In this position the superior part of the capsule (including the coracohumeral ligament) was always found to be quite taut in contrast to the inferior capsule which was always lax except in extreme abduction. Upward dislocation of the humerus was only prevented by the head striking against the overhanging coraco-acromial arch.

## DISCUSSION

Our findings do not support the hypothesis advanced by Cotton and endorsed by Fairbank. In fact, they completely disagree. It is apparent from the electromyographic results that the deltoid, the muscle one would expect to be especially active in preventing downward dislocation of the humerus, is inactive even with heavy pulls. Other muscles running vertically from the scapula to the humerus, particularly the biceps and the long head of triceps, are conspicuously inactive as well. Therefore, there now seems to be little or no reason to doubt that downward dislocation is prevented by the superior part of the capsule along with the supraspinatus (and to a lesser extent the posterior fibers of the deltoid). Strangely enough, these structures run in a horizontal and not in a vertical direction.

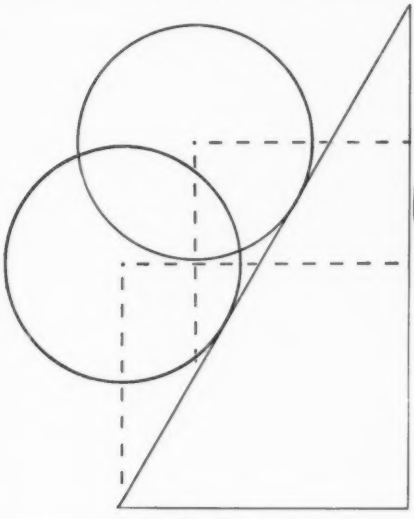

FIG. 2

Fig. 2. A body moved along a slope undergoes displacement in two primary directions—vertical and horizontal. Restricting the movement in one primary direction acts as a lock, preventing movement in the other direction.

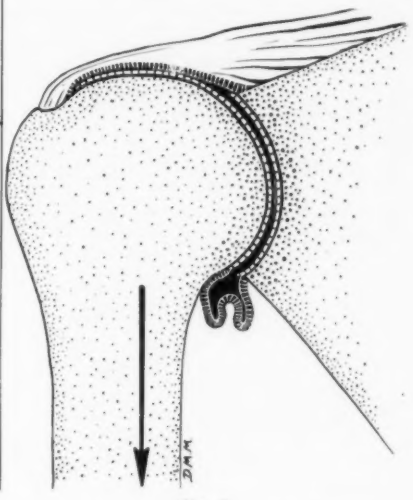

FIG. 3

Fig. 3. The superior part of the capsule of the joint and the associated supraspinatus tighten when the humeral head is pulled downward on the slope of the glenoid fossa.

The mechanism by which these horizontally placed structures succeed is dependent upon a well known, but previously unexplained fact, namely, the obliquity of the glenoid fossa. When the scapula is examined in its correct orientation, invariably it is found to face somewhat upward in addition to forward and laterally (Fig. 1). It now appears that this slope of the glenoid fossa—particularly its lower part—plays an important role in preventing downward dislocation or subluxation. As the head of the humerus is pulled downward, it is, of necessity, forced lateralward because of the slope of the glenoid fossa (Fig. 2). If this lateral movement could be stopped, the result would be a stopping of the downward

movement. The superior part of the capsule of the joint and the supraspinatus (and posterior fibers of the deltoid) are so placed that they can—indeed they must—tighten to prevent the downward dislocation (Fig. 3). Simple as this explanation may seem, it is dependent on our findings that (a) the vertically placed muscles definitely remain relaxed while (b) the supraspinatus (and posterior deltoid) become quite active and (c) the superior part of the capsule becomes taut. The very rareness of downward dislocation of the normal shoulder joint confirms the effectiveness of this locking mechanism.

The ordinary effect of gravity on the unloaded arm is counteracted in many persons by the superior part of the capsule. In this area the coracohumeral ligament forms a real thickening and we suggest that this is an important function of this ligament. With moderate or heavy loads, the supraspinatus is called upon to reinforce the horizontal tension of the capsule although in some persons it is required even without a load. The posterior fibers of the deltoid, imitating in general the direction of the supraspinatus, apparently act in the same way but to a lesser extent.

The mechanism cannot operate when there is abduction of the humerus. As a result, the head can be easily subluxated when it is in this position in the cadaver. Fairbank convincingly demonstrated that subluxation can be also produced in anesthetized normal men but his roentgenograms of the subluxated shoulders show in each case a real degree of abduction of the humerus in relation to the position of the scapula. It would appear that in these unconscious subjects the subluxation was preceded by a drawing downward of the glenoid fossa (that is, relative abduction of the humerus) and thus a neutralization of the locking mechanism.

SUMMARY

An electromyographic study of various muscles in the region of the shoulder joint in twenty-two healthy men combined with a study of dissections shows that, contrary to expectations, downward dislocation of the shoulder joint is not prevented by the vertically running muscles, for example, the deltoid, biceps, and triceps. Normally it is prevented by a locking mechanism dependent on three factors: (1) the slope of the glenoid fossa, leading to (2) the tightening of the superior part of the capsule (including the coracohumeral ligament), and (3) the activity of the supraspinatus muscle (and, to a lesser extent, the posterior fibers of the deltoid).

REFERENCES

1. Basmajian, J. V.: Electromyography of Two-Joint Muscles. Anat. Rec. **129**: 371-380, 1957.
2. Basmajian, J. V.: and Latif, A.: Integrated Actions and Functions of the Chief Flexors of the Elbow. A Detailed Electromyographic Analysis. J. Bone and Joint Surg., **39-A**: 1106-1118, Oct. 1957.
3. Cotton, F. J.: Subluxation of the Shoulder—Downward. Boston Med. and Surg. J., **185**: 405-407, 1921.
4. Fairbank, T. J.: Fracture-Subluxations of the Shoulder. J. Bone and Joint Surg., **30-B**: 454-460, Aug. 1948.
5. Inman, V. T.; Saunders, J. B. DeC. M.; and Abbott, L. C.: Observations on the Function of the Shoulder Joint. J. Bone and Joint Surg., **26**: 1-30, Jan. 1944.

# Intracapsular Fractures of the Femoral Neck

## Comminution of the Posterior Neck Cortex as a Cause of Unstable Fixation *†

BY MAX SCHECK, M.D., SAN FRANCISCO, CALIFORNIA

Non-union in adduction types of intracapsular fractures of the neck of the femur has been reported to occur in 13[3] to 33 per cent[6] of patients treated by internal fixation. Several factors have been held responsible for this comparatively high incidence of non-union. Among these are: poor blood supply to the head, lack of periosteal callus formation, and mechanical factors. The conven-

Fig. 1

Lateral roentgenogram of a recent fracture, showing the anterior angulation between the head and neck fragments and a large butterfly fragment of the posterior cortex.

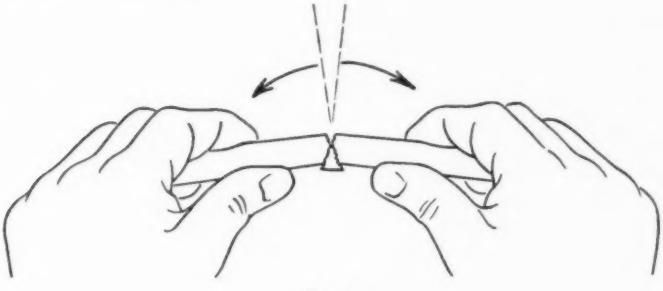

Fig. 2

The mechanism of a compression fracture. Under crossbending, tension develops on the convex side and it breaks. On the concave side, under compression, a butterfly fragment is separated from the two main fragments.

* Based on a paper read at the Annual Meeting of the Western Orthopedic Association, Portland, Oregon, October 23, 1958.

† This study was aided by a research grant from Mount Zion Hospital and Medical Center, San Francisco, California.

TABLE I

SIXTY-NINE* CASES OF INTRACAPSULAR ADDUCTION FRACTURES OF THE NECK OF THE FEMUR

| Procedure | No. of Cases | Union | Non-union |
|---|---|---|---|
| Closed reduction and pinning | 59 | 40 | 19 |
| Open reduction and pinning | 10 | 4 | 6 |
| | 69 | 44 (64 per cent) | 25 (36 per cent) |

*Fourteen other fractures treated by primary subtrochanteric osteotomy or insertion of a prosthesis were not included, and seventeen additional fractures treated by reduction and pinning were not included because of lack of follow-up.

TABLE II

DATA ON FOLLOW-UP PERIOD

| Length of Follow-up | No. of Cases | Union | Non-union |
|---|---|---|---|
| Less than one year | 9 | 0 | 9 |
| More than one year (average, 16.2 months) | 60 | 44 | 16 |
| Total | 69 | 44 | 25 |

tional approach to the mechanical problem is that of Pauwels which concerns only the obliquity of the fracture surface measured on an anteroposterior roentgenogram.

It is not unusual for the fracture fragments to become displaced during the postoperative period despite a satisfactory reduction of the fracture and correct positioning of the pin. This instability is frequently attributed to the obliquity or vertical inclination of the plane of the fracture as emphasized by Pauwels. The frequent occurrence of butterfly fragments of cortical bone on the posterior aspect of the neck, along with the displacement of the fragments as seen on lateral roentgenograms, led me to believe that the obliquity of the fracture described by Pauwels might not be the only cause of instability. Hence, my attention was directed to these cortical-bone fragments as an additional factor leading to instability in certain instances. The comminution which occurs on the posterior aspect of the neck is believed to be caused by compression (Figs. 1 and 2). Comminution of both cortical and cancellous bone was demonstrated by roentgenograms in the majority of these fractures and by actual surgical exposure of a limited number.

## REVIEW OF THE LITERATURE

Forward angulation of the fragments and compression of the posterior aspect of the neck with comminution of the cancellous or cortical bone were noted by several of the earlier writers. Their information was derived from post-mortem specimens [2,5,10] or from fractures produced experimentally in cadavera [7]. Linton, in 1944, reported defects of the posterior aspect of the neck in 55 per cent of his cases, based on his extensive study of roentgenograms.

## MATERIAL

The roentgenograms of 100 randomly selected cases of recent intracapsular fractures of the neck of the femur were studied. In addition, the findings were noted in four patients in which a prosthesis was inserted primarily through a

posterolateral or posterior approach. Fourteen of the 100 patients selected were treated by subtrochanteric osteotomy or insertion of a prosthesis. These patients were not made part of this study. Sixty-nine of the remaining eighty-six patients who were treated by reduction and pinning were followed. In fifty-nine of these patients closed reduction and pinning were done; in ten, open reduction and pinning were done (Table I).

## FOLLOW-UP

The follow-up was limited to the study of roentgenograms because roentgenographic evidence of union or non-union was considered to be the most important criterion for the evaluation of the factors involved. Sixty cases were followed for a minimum period of twelve months; the longest follow-up was forty-eight months, making an average of 16.2 months. In nine patients with obvious non-union included in the study the follow-up period was less than twelve months (Table II).

In eight of these nine cases a secondary osteotomy or insertion of a prosthesis was carried out about six months after pinning. The remaining patient, to be discussed in detail later, died two months after pinning, and autopsy showed non-union. In these cases the fragments were grossly displaced and, undoubtedly, if a second surgical procedure had not been carried out the fractures would have remained ununited.

## METHOD OF STUDY

This study was concerned primarily with the change in alignment of the fragments revealed by anteroposterior and lateral roentgenograms, which could be attributed to instability factors inherent in the type of fracture. For this reason, inadequate reduction and faulty pinning as causes for unstable fixation were eliminated. Nine of the sixty-nine patients in whom there had been adequate follow-up had had grossly inadequate reduction, inadequate pinning, or both. These were therefore omitted in the final assessment. In the remaining sixty patients serial anteroposterior and lateral roentgenograms were examined to ascertain if the pin provided stable fixation. If there was a postoperative change of the alignment of the fragments, the factors which might have caused or contributed to the instability were studied. Fixation was considered to be stable if no postoperative change in the alignment of the fragments occurred other than a slight valgus settling and telescoping as seen on the anteroposterior roentgenogram. In the anteroposterior roentgenogram, unstable fixation was recognized by the development of coxa vara and shortening of the neck. A vertical fracture (Pauwels' Type III) and other known instability factors, such as comminution of the cortex of the inferior aspect of the neck, were noted.

On the lateral views, unstable fixation was recorded when the head was no longer set centrally on the neck but had shifted posteriorly (Figs. 3-A through 3-D). Although the head was set centrally on the neck at the time of reduction, it shifted posteriorly some days, weeks, or months after surgery despite adequate pinning. This shift is real and is not caused by a difference in roentgenographic projection, for, as Evans pointed out, in a lateral roentgenogram of a normal femur the head is seen to be set centrally on the neck, whatever the degree of rotation of the femur. The lateral roentgenograms of all cases were examined for evidence of fragmentation of the cortical bone or compression of the trabecular bone on the posterior aspect of the neck.

## FINDINGS

Union was obtained in forty-four of the sixty-nine patients (64 per cent) treated by reduction and pinning (Table I). In nine of the sixty-nine patients there was unsatisfactory reduction, or an unsatisfactory pinning, or both; non-union resulted in all. In twenty-nine of the sixty patients in which there were

FIG. 3-A

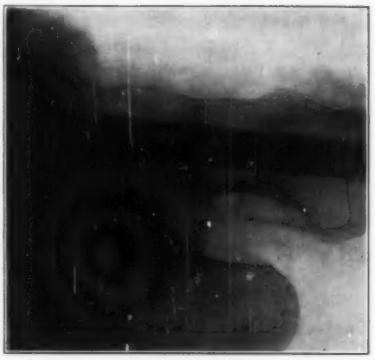

FIG. 3-B

Fig. 3-A: Case 12. Lateral roentgenogram made in the operating room after reduction and pinning. The head is set centrally on the neck. Note the comminution on the posterior aspect.
Fig. 3-B: One week after operation, the head fragment is shown to have shifted posteriorly from its central position.

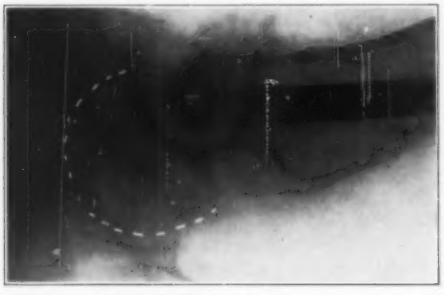

FIG. 3-C

FIG. 3-D

Fig. 3-C: Four week after operation, a further posterior shift is shown.
Fig. 3-D: Six months after operation, the shift is shown to be quite marked. A step has formed between the cortex of the neck and the head (arrow).

satisfactory reduction and pinning, a postoperative change in alignment of the fragments was shown on either the anteroposterior or lateral, or both, roentgenograms (Table III). Thirteen of these fractures united; sixteen did not unite. In thirty-one cases there was no shift of the fragments. In Table III the influence of stable internal fixation on the outcome of this fracture is shown.

*Unstable Fixation and Union*

Of the twenty-nine fractures in which a postoperative shift of the fragments occurred, thirteen united despite this (Table IV). In one there was both a varus and a posterior shift, in three there was only a varus shift, and in nine there was only a posterior shift. The nine fractures, in which the femoral head did not shift into varus, had been overreduced according to McElvenny's concept. Since varying degrees of posterior settling of the head occurred in all of these nine fractures, it would appear that overreduction with the head in valgus position was a stabilizing factor which offset the effects of compression or comminution of the posterior part of the neck.

*Unstable Fixation and Non-union*

However, overreduction with the head in valgus position did not always ensure stability and union. In the sixteen fractures in which non-union occurred, despite adequate reduction and pinning (Table V), five were in perfect valgus

TABLE III

INFLUENCE OF UNSTABLE FIXATION ON UNION IN SIXTY CASES WITH ADEQUATE PINNING AND ACCEPTABLE REDUCTION

| | No. of Cases | Union | Non-union |
|---|---|---|---|
| Postoperative shift of fragments | 29 | 13 ( 45 per cent) | 16 (55 per cent) |
| No postoperative shift | 31 | 31 (100 per cent) | 0 |

TABLE IV

CHANGE OF ALIGNMENT AFTER OPERATION IN THIRTEEN FRACTURES WITH UNION

| Case | Change of Alignment of the Fragments on the Anteroposterior Film | Change of Alignment of the Fragments on the Lateral Film |
|---|---|---|
| 4 | − | + |
| 12 | − | + |
| 17 | − | + |
| 26 | − | + |
| 31 | − | + |
| 32 | − | + |
| 37 | − | + |
| 43 | − | + |
| 46 | + | − |
| 48 | − | + |
| 51 | + | + |
| 83 | + | − |
| 84 | + | − |
| | 4 fractures with varus shift<br>9 fractures without varus shift | 10 fractures with posterior shift of the head fragment<br>3 fractures without posterior shift of the head fragment |

+ signifies that a shift occurred; − signifies that a shift did not occur.

position. In all five the non-union appeared to result purely from posterior displacement of the head fragment; Case 92 is representative of this group of cases. An excellent valgus reduction was obtained; on the lateral roentgenogram the head was seen to be situated centrally on the neck. A butterfly fragment of cortical bone from the posterior aspect of the neck could be seen on the lateral roentgenogram. A low Smith-Petersen pin and a threaded Steinmann pin were used for internal fixation (Figs. 4-A and 4-B). Twelve days later, alignment on the anteroposterior roentgenogram was still shown to be excellent, but on the lateral film it was seen that the head had shifted somewhat posteriorly. This shift became more pronounced, as shown in a lateral roentgenogram made nineteen days after surgery (Figs. 4-C and 4-D). This patient died two months later of intercurrent disease. At autopsy, the upper half of the fractured right femur was removed. The fragments were not united and the head could be rocked back and forth in an anteroposterior direction. Whenever the head was moved backward, the pins protruded further from the cortex of the lateral aspect of the subtrochanteric region. The specimen when seen from in front (Fig. 4-E) showed good position of the fragments, but when viewed from behind and from its inferior surface (Figs. 4-F and 4-G) it was apparent that the head had rotated posteriorly and that the length of the neck on its posterior aspect was markedly reduced. The

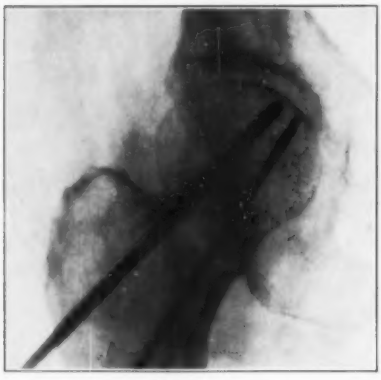

FIG. 4-A

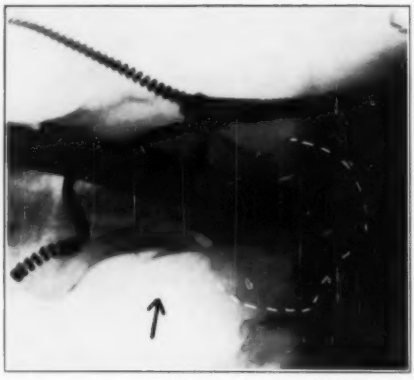

FIG. 4-B

Fig. 4-A: Case 92. Anteroposterior roentgenogram, showing good reduction.
Fig. 4-B: Lateral roentgenogram made at surgery after reduction and internal fixation by a Smith-Petersen pin and threaded Steinmann pin. Note the comminution of the posterior aspect of the neck.

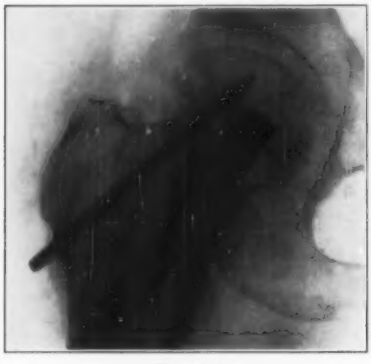

FIG. 4-C

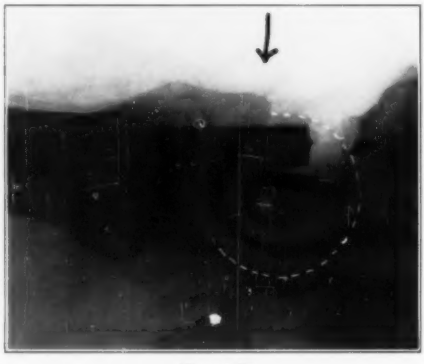

FIG. 4-D

Fig. 4-C: Anteroposterior roentgenogram, made nineteen days after operation.
Fig. 4-D: Lateral roentgenogram made nineteen days after operation; further posterior shift of the head fragment and step formation between the cortex of the anterior aspect of the neck and the head (arrow) are shown.

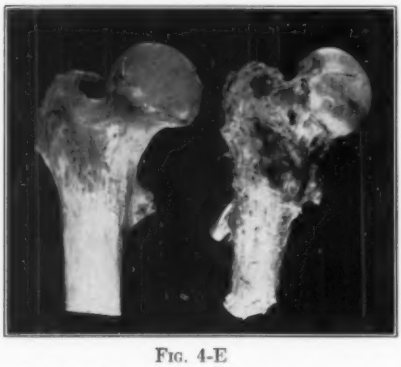

FIG. 4-E

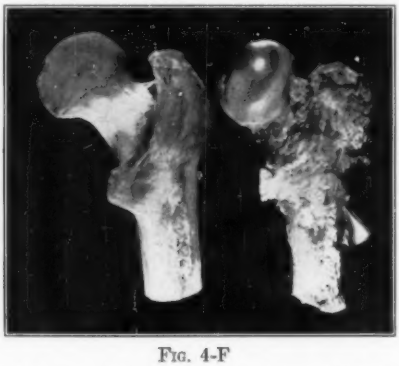

FIG. 4-F

Fig. 4-E: Front view of the specimen; good alignment and maintenance of length of the cortex of the anterior aspect of the neck are shown. A normal femur is on the left.
Fig. 4-F: The specimen as seen from behind; the head has rotated posteriorly and the cortex of the posterior aspect of the neck is reduced in length.

preservation of the cortex of the anterior aspect of the neck, the reduction in length of the cortex of the posterior aspect of the neck, the posterior rotation of the head, and the step formation between the cortex of the anterior aspect of the neck and the head were clearly seen.

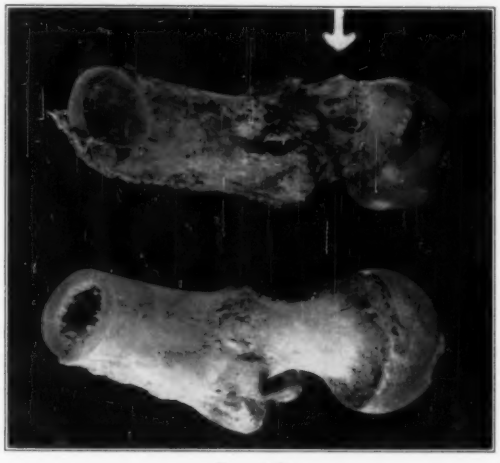

FIG. 4-G

The neck as seen from its inferior surface; this view is comparable to the lateral roentgenogram. Note the step formation (arrow) between the cortex of the anterior aspect of the neck and the head, the posterior settling of the head fragment, and the discrepancy in length between the cortex of the anterior and posterior aspects of the neck.

TABLE V

CHANGE IN ALIGNMENT AFTER OPERATION OF THE FRAGMENTS IN SIXTEEN FRACTURES WITH NON-UNION

| Case | Change of Alignment of the Fragments on the Anteroposterior Film | Change of Alignment of the Fragments on the Lateral Film |
|---|---|---|
| 16 | + | + |
| 19 | − | + |
| 21 | + | + |
| 49 | + | − |
| 52 | + | − |
| 58 | − | + |
| 66 | − | + |
| 69 | + | − |
| 77 | + | + |
| 78 | + | + |
| 80 | + | − |
| 82 | − | + |
| 86 | + | − |
| 88 | + | + |
| 89 | + | + |
| 92 | − | + |
| | 11 fractures with varus shift<br>5 fractures without varus shift | 11 fractures with posterior shift of the head fragment |

+ signifies a shift occurred; − signifies a shift did not occur.

FIG. 5-A

FIG. 5-B

Fig. 5-A: Case 1. Unsuccessful reduction. The head fragment is shown to be in varus position, and the fragments show only about 50 per cent apposition.

Fig. 5-B: Lateral roentgenogram, showing a large cortical fragment apparently lying within the fracture gap.

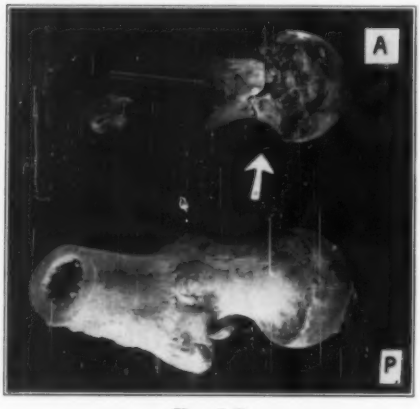


FIG. 5-C

FIG. 5-D

Fig. 5-C: The head and neck are seen from the inferior surface. The removed head and portion of the neck are shown above. The loose posterior cortical-bone fragment is fitted into the defect of the cortex of the posterior aspect of the neck (arrow). (The rounded object at the end of the lower wire is a piece of clay used for support.) A normal femur is shown below.

Fig. 5-D: The size of the loose fragment is shown. The head and neck are seen from behind.

In the remaining eleven fractures in this group, a varus shift occurred owing to the obliquity of the plane of the fracture (Pauwels' Type III) or comminution of the inferior aspect of the neck. In six of these fractures a posterior shift of the head fragment was found as well. Thus, in the sixteen cases of non-union there were eleven cases with posterior shift of the head fragment (five with posterior shift alone, and six with combined posterior and varus shift) and five with varus shift alone.

*Frequency of Comminution of the Cortical Bone on the Posterior Aspect of the Neck*

The lateral roentgenograms of the 100 randomly selected fractures, regardless of the method of treatment or the adequacy of follow-up, were reviewed to determine the incidence of comminution of the cortex of the posterior surface of the femoral neck and the incidence of compression of the cancellous bone in the

posterior portion of the head and neck. Butterfly fragments of the cortex, both large and small, were seen in fifty-two of these fractures in the lateral roentgenograms made in the operating room. In another ten—making a total of sixty-two—similar fragments were first seen in the postoperative films, apparently because of differences of the roentgenographic projections. In the patients with large butterfly fragments on whom further surgery was performed, with exposure of the fracture site, these fragments were found to range in size from 1.5 by 1.5 to 1.5 by 2.0 centimeters.

*Operative Findings*

Primary insertion of a prosthesis in four additional cases provided an opportunity to gain further information on the comminution which occurs on the posterior aspect of the neck in these fractures.

R. G., a woman thirty-five years old, suffered a displaced comminuted fracture of the neck of the right femur. A closed reduction by McElvenny's maneuver was attempted. Postreduction roentgenograms showed that the head remained in varus position and the fragments were distracted. A large fragment of cortical bone from the posterior surface of the neck was noted on the lateral roentgenogram, apparently lying within the fracture gap (Figs. 5-A and 5-B). Since this reduction was not acceptable and the patient also had advanced multiple sclerosis, a prosthesis was inserted. As the posterior aspect of the neck was exposed by a posterolateral approach, a large fragment of cortical bone, completely devoid of soft-tissue attachment, appeared. It measured one by two centimeters and could be fitted into a defect on the posterior aspect of the neck (Figs. 5-C and 5-D). After this fragment was removed and the head and neck fragments were aligned anteriorly, a large defect was apparent on the posterior aspect between the cortex of the neck and the head fragment.

L. D. B., a woman eighty-one years old, had a subcapital fracture of the neck of the left femur with typical displacement and roentgenographic evidence of comminution of the cortex of the posterior surface of the neck (Fig. 6-A). Closed reduction was not successful, and a prosthesis was inserted. The fracture was exposed through a posterolateral approach. Considerable rotation of the head fragment had occurred. Several smaller fragments of the cortical bone derived from the cortex of the posterior aspect of the neck were attached to the adjacent region of the head by the retinaculum of Weitbrecht (Figs. 6-B and 6-C).

M. A., a woman sixty-eight years old, sustained an adduction fracture of the neck of the left femur. Pinning was undertaken, but reduction and internal fixation were unsatisfactory. A lateral roentgenogram made eight days later showed a large fragment of cortical bone from the posterior surface of the neck. Ten days after operation the pin had disengaged from the head, and a prosthesis was inserted through a posterolateral approach. When the fracture was exposed, a large fragment of cortical bone was seen on the posterior aspect. It had no soft-tissue attachment and could be fitted into a defect in the cortex of the posterior aspect of the neck. Owing to this posterior defect, the anterior surface of the neck was much too long, and a substantial portion of it had to be trimmed off in order to prepare the stump of the neck to fit the prosthesis.

G. L., a man eighty-nine years old, sustained an intracapsular fracture of the neck of the femur which was treated by primary insertion of a prosthesis. The surgical approach was posterior. When the fracture was exposed there was no butterfly fragment of cortical bone to be found, but when the fracture was reduced by traction and internal rotation of the distal fragment, a large gap appeared between the head and the posterior aspect of the neck. This defect could only be explained as having resulted from compression of the cancellous bone and minor comminution of the cortex of the posterior aspect of the neck.

Late sequelae, such as aseptic necrosis and degenerative arthritis of the hip joint, were not studied because the follow-up period, although sufficient for the purpose of this investigation, was not long enough for the study of these later complications.

## DISCUSSION

*The Mechanism of the Fracture*

The examination of the initial lateral views of recent fractures showed a typical angulation between the head and neck fragments in eighty-nine of 100

FIG. 6-A

Lateral roentgenograms, showing comminution of the cortex of the posterior aspect of the neck.

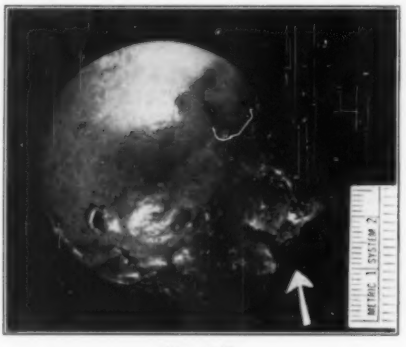

FIG. 6-B

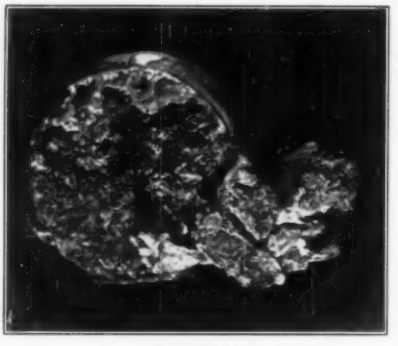

FIG. 6-C

Fig. 6-B: The removed femoral head as seen from in front. There are several cortical fragments (arrow) attached to the posterior aspect of the head by the retinaculum of Weitbrecht.
Fig. 6-C: The viewer faces the fracture surface of the head. The cortical fragments of the posterior aspect have been turned sideways for better demonstration.

fractures. The apex of the angle was anterior and the angle was open backward. The head was frequently rotated posteriorly. This incidence is so high that the displacement cannot be fortuitous but must be caused either by the fracture mechanism or by forces acting on the fragments subsequent to the fracture. Although the anteroposterior views showed some upward displacement of the neck, contact between the fragments was still maintained. Since the fragments are hard and relatively incompressible, forward angulation at the fracture site must cause the cortex of the posterior aspect of the neck to gouge out the cancellous bone of the head (Fig. 7) or else it must break off a cortical fragment from the posterior aspect of the neck. In the original lateral roentgenograms butterfly fragments of the cortex on the posterior aspect of the fracture were visualized in only a small number of the cases studied. This results from the overlap of the main fragments which is ordinarily present in the initial lateral view. Only after the fracture has been reduced by traction and internal rotation will the butterfly fragment, if present, be visible in the lateral view.

The typical anterior angulation and the frequency with which comminution of the posterior surface of the neck occurs support the opinion that this fracture is caused by compression, as expounded by previous observers. The head and

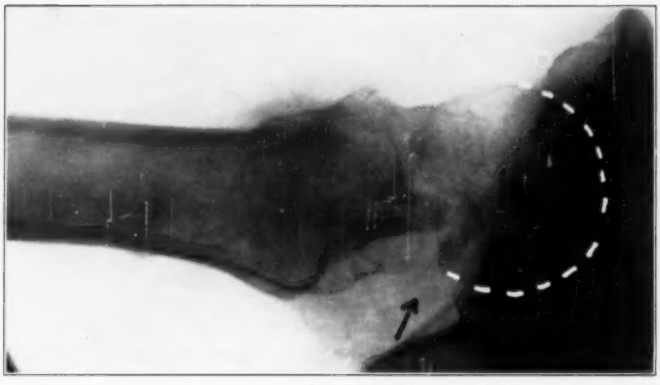

FIG. 7

The intrusion of the cortex of the posterior aspect of the neck into the cancellous structure of the head is clearly shown in this film (arrow).

neck of the femur have a curved longitudinal axis, the convexity of which is directed anteriorly. Force applied to the femoral neck from the direction of the lateral aspect of the greater trochanter, whether by a fall on the hip or by intrinsic muscle forces, causes the cortex of the anterior aspect of the neck to fail in tension and the posterior cortex to fail in compression with separation of a butterfly fragment or compression of the cancellous bone. This conclusion is in accord with the observations made on autopsy specimens by Bigelow, Frangenheim, and Odelberg-Johnson. The findings in the present study also support Kocher's concept of the mechanism of this fracture. He produced fractures on cadavera by either a direct blow on the greater trochanter or by a blow in the long axis of the femur with simultaneous external rotation of the extremity. He believed that the head was fixed firmly by the anterior capsule and the iliofemoral ligament while the neck rotated posteriorly. The posterior cortex of the femoral neck then impinged against the posterior rim of the acetabulum, and the neck buckled. This caused the posterior cortex of the neck to dig into the spongiosa of the head. Kocher called it a "Scharnierfraktur". Bigelow, as cited by Linton, thought that a hinge movement takes place between the head and neck fragments around an axis almost perpendicular to the long axis of the neck. He called it a hinge fracture, as did Kocher later on. Applying forces such as compression, bending, torsion, or combinations thereof on ninety-nine femora of fresh cadavera, Backman produced twelve subcapital and sixty transcervical fractures. Only two subcapital fractures produced in this manner showed fracture lines which were in close accord with the pattern usually seen *in vivo*. The flat, smooth appearance of the fracture surfaces which are observed in transcervical fractures *in vivo* and Backman's findings in post-mortem specimens led him to assume that shearing forces are predominant in the production of these fractures. In the bending of short beams shearing forces are large since the bending movement is small because of the short lever. Backman postulated that in falls on the posterior aspect of the hip the gluteal muscles are compressed as a cushion against the posterior aspect of the head and neck, thereby supporting the neck on its posterior aspect and shortening the femoral-neck lever. He tested this hypothesis by applying dynamic forces to ten femora with the neck supported from behind with sponge rubber or modeling clay. The resulting fractures resembled the transverse cervical fractures which are seen in living persons in most instances.

The conclusions of the present study are in partial agreement with those of Backman since compression, bending, and retroflexion are considered to be important factors in the mechanism causing the fracture. However, the frequent

occurrence of comminution of the posterior cortex of the femoral neck in the present study leads to the assumption that either there is an impact against the posterior cortex or the posterior aspect of the neck is fractured by bending against a fulcrum. It seems improbable that the gluteal muscles can provide such a fulcrum; Kocher's concept that the posterior rim of the acetabulum impinges against the posterior aspect of the neck as it rotates posteriorly seems to be a more acceptable explanation for the fractures observed.

*Comminution of the Posterior Cortex or Compression of the Cancellous Bone of the Head and Neck as Causes of Instability after Reduction and Fixation*

Comminution of the cortex of the posterior surface of the neck was found in 62 per cent of the fractures in this series. This figure agrees quite well with Linton's findings that defects of the posterior aspect of the neck occurred in 55 per cent of his cases. From an extensive study of roentgenograms he found defects of the posterior aspect of the neck in 137 of 248 fractures. He believed that the

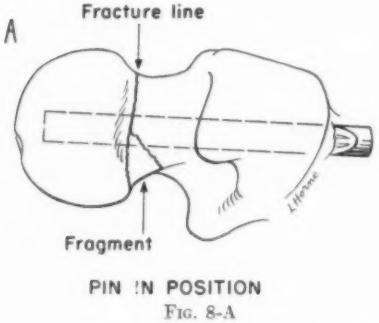


FIG. 8-A

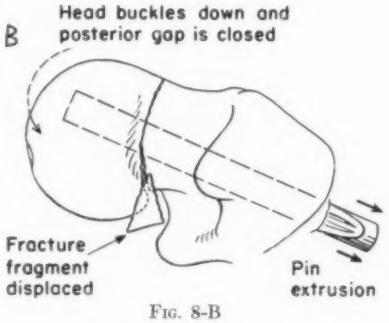


FIG. 8-B

Figs. 8-A and 8-B: Effects of comminution of the posterior aspect on pin protrusion and tendency of the extremity to return into external rotation.
Fig. 8-A: With the leg in internal rotation on the fracture table, the neck is horizontal. The posterior defect is opened up.
Fig. 8-B: Despite internal fixation, the leg tends to return into external rotation during the postoperative period because the posterior defect closes. Early nail protrusion due to posterior settling of the head and telescoping of the fragments is shown.

defects were due to a compression of the posterior parts of the femoral neck. However, Linton did not find an appreciably greater incidence of non-union in the cases with defects of the posterior aspect. He nevertheless expressed the opinion that a large defect of the posterior aspect of the neck was a considerable obstacle to union.

The study of serial lateral roentgenograms, as advocated in this study, showed that a posterior shift of the head fragment occurred in twenty-one of sixty fractures in which the reduction and pinning were adequate. Analysis of the sixteen fractures with non-union which occurred in this group of sixty fractures revealed that compression and fragmentation of the posterior aspect of the femoral neck appeared to be the sole cause of non-union in five cases and at least one of the factors causing instability in six others. Thus, fragmentation of the posterior surface of the neck, alone or in combination with other factors causing instability, was responsible for non-union in eleven of sixteen cases. It is not suggested that non-union will always occur in association with compression of the posterior aspect of the neck. As shown in Table III, nine fractures united despite a posterior shift of the head fragment with respect to the neck. However, in all nine cases an overreduction of the head had been accomplished according to McElvenny's concept. Thus, it appears that by this type of reduction these fractures were

spared from non-union. On the other hand, the combination of a varus shift with a posterior shift of the head fragment was responsible for six of the sixteen cases of non-union. The tendency for the extremity to return to external rotation despite internal fixation is most readily explained by the comminution or the defect which occurs on the posterior aspect of the neck. Early protrusion of the nail is a frequent finding in unstable fractures. In my opinion it is caused by the *vis a tergo* applied to the end of the nail by the posterior settling of the head and telescoping of the fragments (Figs. 8-A and 8-B).

*Suggested Clinical Applications*

If a large butterfly fragment of cortical bone is separated from the posterior aspect of the neck, the remaining portion of the neck will be shorter on its posterior than on its anterior aspect. The plane of the fracture surface on the intact portion of the neck will therefore be oblique, not only when viewed in the anteroposterior projection (Pauwels' angle) but also when viewed in the lateral projection since the fracture surface will incline from the anteromedial to the posterolateral aspect of the neck. Under these circumstances, when the fragments are reduced by internal rotation and traction, only the anterior portions of the fracture surfaces of the head and neck will make contact, and the stability of the fragments after nailing will be greatly reduced. If an open reduction is performed in this situation, the anterior portion of the neck should be trimmed back until it is on a level with the intact posterior cortex in order to make the plane of the fracture surface perpendicular to the long axis of the neck in an anteroposterior direction. No reference to the concept has been found in the literature, and as yet I have not had the opportunity to try this procedure on an actual fracture.

Since the combination of comminution of the cortex of the posterior aspect of the neck, a Pauwels' Type III obliquity, and comminution of the cortex of the inferior aspect of the neck frequently are associated with an unsatisfactory reduction, instability, and non-union, primary insertion of a prosthesis is advisable in older people.

## SUMMARY AND CONCLUSIONS

1. Most adduction-type intracapsular fractures of the neck of the femur are compression fractures with comminution occurring on the posterior aspect of the neck. Butterfly fragments of the posterior cortex were seen on lateral roentgenograms in sixty-two of 100 fractures which were studied regardless of the method of treatment or the adequacy of the follow-up.

2. Of these 100 fractures, sixty with adequate internal fixation and follow-up were considered suitable for the study of the effect of fragmentation and compression of the posterior aspect of the neck on the stability of the fragments after reduction and internal fixation. A well placed pin did not prevent the head from settling posteriorly in twenty-one of these sixty fractures. In fifteen of these twenty-one fractures there was major comminution of the cortex on the posterior aspect of the femoral neck as seen in the lateral roentgenograms, and in the remaining six it is believed that compression of cancellous bone was responsible for the posterior shift of the head fragment.

3. Compression and fragmentation of the posterior cortex of the neck are important factors leading to instability. Compression and fragmentation, alone or in combination with other well established factors, caused unstable internal fixation and non-union in eleven of sixteen fractures in which the reduction and pinning had been considered satisfactory.

4. Overreduction with the head in a valgus position by the method of McElvenny was a stabilizing factor which in nine fractures counteracted the adverse effect of compression and fragmentation of the cortex of the posterior aspect of the neck.

5. The combination of compression and fragmentation of the posterior aspect of the neck with other instability factors, such as a vertical or oblique plane of the fracture (Pauwels' Type III) or comminution of the inferior aspect of the neck, was responsible for non-union in six of the sixteen fractures in which the initial treatment appeared adequate.

REFERENCES

1. Backman, Stig: The Proximal End of the Femur. Acta Radiol., Supplementum 146, 1957.
2. Bigelow, H. J.: The Mechanism of Dislocation and Fracture of the Hip. Philadelphia, Henry C. Lea, 1869.
3. Boyd, H. B., and George I. L.: Complications of Fractures of the Neck of the Femur. J. Bone and Joint Surg., **29:** 13-18, Jan. 1947.
4. Evans, D. L.: Legg-Calvé-Perthes' Disease. A Study of Late Results. J. Bone and Joint Surg., **40-B:** 168-181, May 1958.
5. Frangenheim, Paul: Studien über Schenkelhalsfrakturen und die Vorgänge bei ihrer Heilung. Deutsche Zeitschr. f. Chir., **83:** 401-455, 1906.
6. Green, J. T., and Gay, F. H.: High Femoral Neck Fractures Treated by Multiple Nail Fixation. Clin. Orthop., **11:** 177-183, 1958.
7. Kocher, Theodor: Beiträge zur Kenntnis einiger praktisch wichtiger Fracturformen. Basel und Leipzig, C. Sallman, 1896.
8. Linton, P.: On the Different Types of Intracapsular Fractures of the Femoral Neck. A Surgical Investigation of the Origin, Treatment, Prognosis and Complications in 365 Cases. Acta Chir. Scandinavica **90:** Supplementum 86, 1944.
9. McElvenny, R. T.: The Immediate Treatment of Intracapsular Hip Fractures. Clin. Orthop., **10:** 289-323, 1957.
10. Odelberg-Johnson, G.: Zur Entstehung der medialen Kollumfraktur. Acta Chir. Scandinavica, **67:** 595-617, 1931.
11. Pauwels, Friedrich: Der Schenkelhalsbruch ein mechanisches Problem. Grundlagen des Heilungsvorganges Prognose und kausale Therapie. Beilageheft zur Zeitschrift für Orthopädische Chirurgie, Vol. 63. Stuttgart, Ferdinand Enke, 1935.

# Femoral-Shaft Fractures in Children

## Treatment by Closed Reduction and Double Spica Cast Immobilization *

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Children with fractures of the femoral shaft have been treated in Raleigh for the past twenty-four years by closed reduction and plaster-of-Paris immobilization. An evaluation was made of this method of treatment and of the long-term results. We reviewed the clinical records of 100 unselected patients; fifty-three returned for follow-up examination and roentgenographic study.

Fractures of the femur were first treated by closed manipulation and immobilization in a single hip spica by Harvey Cushing in 1898 at the Johns Hopkins Hospital [5,6]. Cushing used a single spica cast with much padding and as a result had no countertraction within the cast. No distinction was made between femoral fractures in children and those in adults. Cushing had to depend on fluoroscopic examination and hence had difficulty in visualizing the position of the fracture within the cast. For these reasons some of his results were poor and his method was not generally accepted.

In the early 1930's one of us (H.A.T.) adopted a modified Hoke traction spica with fixed skin traction for the treatment of femoral fractures in children [9]. The children were allowed to return to their homes after twenty-four hours of hospitalization. This method was discarded in favor of a double spica cast when difficulty was encountered with the skin traction while the patients were at home. No difference in the end results was noted between those patients treated with the Hoke plaster fixed traction apparatus and those treated in a double plaster spica. It was thought that adequate immobilization of the fracture practically eliminated muscle spasm since there was very little tendency for shortening to occur with either method. It was true, however, that the families could care for the patients in the double plaster spica more easily. The several physicians who treated the patients in this series were instructed in this method by Thompson.

### PRINCIPLES

Certain basic principles apply universally to the treatment of femoral-shaft fractures in children [11]:

1. The simplest form of satisfactory treatment is the best.
2. Whenever possible the initial treatment should be the permanent treatment.
3. Perfect anatomical reduction is not essential for perfect function.
4. The restoration of alignment of the fragments is more important than the position of the fractured surfaces with respect to one another.
5. The more growth remaining in the fractured femur, the more likelihood there is of restoration of normal bone architecture as the bone grows after healing of the fracture.
6. Overtreatment is usually worse than undertreatment.
7. The injured limb should be immobilized in a Thomas splint before definitive therapy is begun, until there is no danger to the patient or the limb. Prolonged elevation of the limb of a child with incipient shock should be avoided [8,10].

The hope that all deformities in children will correct themselves spontane-

*Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, New York, N.Y., February 2, 1958.

ously is no excuse for leaving a deformity which could be corrected by simple means. At the same time, it is unwise to subject a child to frequent manipulations or undue trauma in order to correct minor displacement [7].

## METHOD

As soon as the patient's general condition warrants and the proper facilities are available, the child is anesthetized. If skeletal traction is to be used a Kirsch-

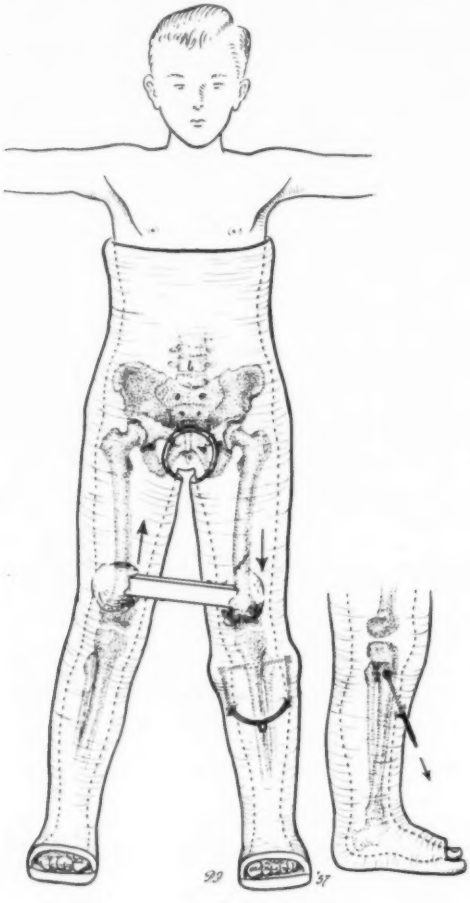

FIG. 1

Drawing illustrating the principle of well-leg traction to prevent overriding or angulation. A carefully molded cast without excessive padding is essential. The amount of flexion and abduction of the affected limb in the cast is determined by the position of the fracture and direction of muscle pull on the proximal fragment.

ner wire is inserted just distal to the proximal tibial epiphysis on the affected side and a sterile Kirschner-wire bow is attached (Fig. 1). Traction is applied to the Kirschner-wire bow and the patient is transferred to the fracture table. The foot on the unaffected side is fixed in the foot piece of the fracture table, with the knee extended. This is used as countertraction opposing the force applied to the fractured femur through the Kirschner wire. An assistant steadies the pelvis man-

FIG. 2

Case 30. An oblique fracture of the mid-third of the shaft of the right femur of a five-year-old child. This patient was anesthetized, treated by manipulation, and a double spica cast without a Kirschner wire was applied. Roentgenograms of the femur, made six years after injury, show a normal contour of the femoral shaft (bottom panel). This femur is two-sixteenths of an inch shorter than the left femur as measured from standing roentgenograms.

ually as traction is instituted on the fractured thigh. Ordinarily, no additional manipulation is required for the reduction of oblique fractures. Care must be taken to direct the traction so that the pull on the distal fragment will be in line with the proximal fragment. Roentgenograms are made, and the direction of the traction altered, as necessary, to correct any angulation, if it is present. A carefully molded double spica plaster-of-Paris cast is applied from the nipple line to include both feet, incorporating the Kirschner-wire bow in the plaster. The patient is allowed to go home on the following day provided other injuries do not delay his discharge. The casts are usually removed after eight weeks. In children over ten, immobilization is continued in the cast for two to four additional weeks. Union is checked by roentgenographic examination and when satisfactory the child is allowed to be up and around as he wishes.

Kirschner wires were not used in any child less than three years of age or in children with very little displacement of the fracture (Fig. 2). One of us (H.A.T.) did not use the Kirschner wire in any of his patients. The results obtained in his patients were similar to those obtained in patients treated with a Kirschner wire. When a double spica was applied without using skeletal traction, the following technique was employed. The patient was placed on a fracture table with both feet secured to the foot pieces with butterfly knots. On the affected side the hip and knee were flexed 20 degrees or more, depending on the type of fracture. The fracture table was adjusted so that traction would be applied to the affected limb and an upward thrust given on the sole of the foot of the uninvolved limb with the knee and hip on this side extended. In this way the pelvis was tilted downward on the side of the fracture. With the child under full anesthesia, the fracture table was adjusted and the position of the fracture checked by roentgenograms. When the position was satisfactory, padding was carefully applied

FIG. 3

Case 2. Serial roentgenogram of an eighteen-month-old child with a subtrochanteric fracture of the right femur. The second and third roentgenograms in the top panel show the position of the fracture after manipulation. The first two roentgenograms on the bottom panel show the position of the fracture at the time the cast was removed. The lower right roentgenogram shows the valgus position of the affected femur one and one-half years after injury. The proximal fragment in children with subtrochanteric fractures has a tendency to adduct in contrast to adults, where it tends to abduct.

conforming to the contour of each limb and the torso up to the nipple line. Not too much padding should be used—just enough to protect the skin and soft tissues. The plaster spica must be applied carefully and molded to fit well. Initially, the cast was extended down each limb to end mid-way between the calf and ankle. After the plaster had set with the patient still under full anesthesia, the feet were released from the foot pieces and the butterfly knots removed. After carefully padding the feet and ankles the cast was extended down to the toes. If the cast had been applied smoothly and accurately, the fracture was well immobilized and there was little or no pain. Consequently, no muscle spasm developed after anesthesia, and there was very little reason for shortening to occur.

The method for treating transverse fractures of the femoral shaft was essentially the same as that for oblique fractures. One attempt was usually made to engage the fragments end on after the traction had been instituted on the frac-

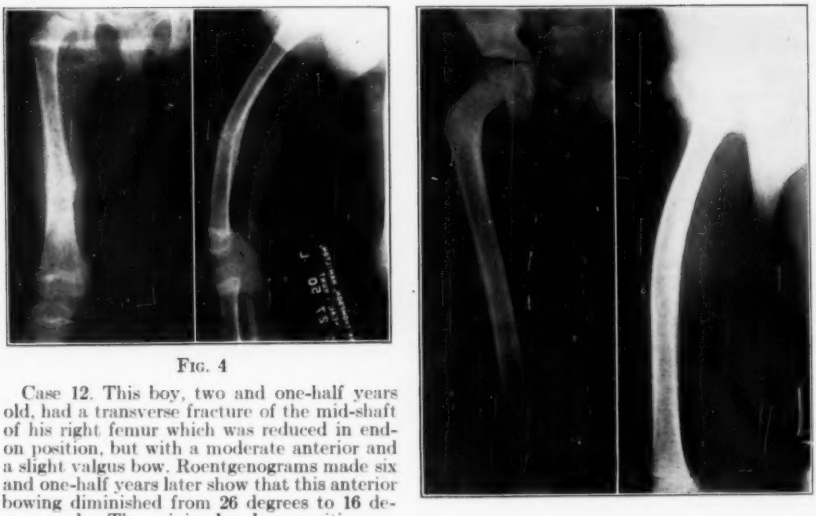

FIG. 4

Case 12. This boy, two and one-half years old, had a transverse fracture of the mid-shaft of his right femur which was reduced in end-on position, but with a moderate anterior and a slight valgus bow. Roentgenograms made six and one-half years later show that this anterior bowing diminished from 26 degrees to 16 degrees only. The minimal valgus position remains the same. One should not expect time to correct angulatory deformities in children with femoral-shaft fractures.

ture table. End-on locking was obtained in some patients, but not in the majority. The procedure employed was first to accentuate the angulation of the fracture greatly while the traction was continued. The ends of the fragments were then locked, if possible, and the proper alignment restored. Any residual angulation was corrected by altering the direction of the traction. Transverse fractures could be engaged at times by distracting the bone ends with traction, manipulating them manually, and then gradually reducing the traction. If this method is used, care must be taken not to immobilize the fracture in a distracted position, and not to injure the soft tissues.

Sometimes it was necessary to employ a muslin sling around the thigh at the apex of the angulation to restore normal alignment. If this is done it is important to use glazed cotton both under and over the muslin so that it can be easily removed as the cast is setting and the plaster is being molded. These slings should never be left within casts as they may cause constriction.

Fractures in the subtrochanteric region (usually transverse) can be treated successfully by this method. The proximal fragment in children can be expected to be flexed acutely and adducted by the pull of the iliopsoas. Therefore, the distal fragment also must be flexed acutely and adducted slightly in order to restore proper alignment (Fig. 3).

We have not intentionally left any patient with more than 0.5 of an inch of overriding. We have made persistent attempts to correct any angulation which might be present. No angulation of more than 10 degrees anteriorly should be left uncorrected. No discernible lateral angulation should be accepted.

## CLINICAL FOLLOW-UP

The hospital and out-patient records of 100 children with fractured femoral shafts were examined. The patients' ages varied from six weeks to fourteen years. The onset of puberty was the arbitrary age limit. The average age of patients treated was 5.5 years. Although this method has been used satisfactorily in children less than three months old, infants are more difficult to care for in a spica, and other forms of treatment are preferable. There were no sequelae from the Kirschner wires in those patients in whom it was used. There were no patients whose fractures took longer than three months to heal. No open reductions were

TABLE I

| Case | Age at Time of Injury | Type of Fracture | Result of Manipulation | Type of Treatment | Age at Last Examination (*Years*) | Relative Length of Affected and Unaffected Limbs at Last Examination (*Inches*) | Gain or Loss in Length at Last Examination as Compared with Length at Cast Removal (*Inches*) | X-ray Contour |
|---|---|---|---|---|---|---|---|---|
| 1. R.R. | 7 mos. | Spiral, mid-third | Length restored | Plain double spica cast | 2 | Even | 0 | Position excellent |
| 2. S.D.T. | 18 mos. | Subtrochanteric, transverse | Some valgus, not end on | Plain double spica cast | 3 | +4/16 | +4/16 | Slight valgus |
| 3. B.B. | 18 mos. | Spiral, mid-third | Length restored | Hoke traction | 20 | Even | 0 | Position excellent |
| 4. S.O. | 22 mos. | Transverse, mid-third | 50 per cent apposition | Plain double spica cast | 11½ | Even | 0 | Normal |
| 5. C.S. | 22 mos. | Long oblique, mid-third | Less than 1/4 in. shortening (almost anatomical) | Plain double spica cast | 11½ | −3/16 | 0 | Normal |
| 6. V.T.H. | 23 mos. | Transverse, mid-third | Remanipulation after 7 days; length restored; no apposition | Hoke traction | 15 | +8/16 | +8/16 | Normal |
| 7. C.K.T. | 2 yrs. | Transverse, upper third | 25 per cent apposition | Plain double spica cast | 3½ | +4/16 | +4/16 | Slight anterior bow |
| 8. H.G.J | 2 yrs. | Transverse, mid-third | 10/16 in. overriding | Plain double spica cast | 8 | Even | +10/16 | Normal |
| 9. D.B. | 2 yrs. | Oblique, mid-third | Length restored | Plain double spica cast | 5 | Even | 0 | Normal |
| 10. C.C. | 2 yrs. | Oblique, mid-third | Anatomical | Plain double spica cast | 5 | +2/16 | +2/16 | Normal |
| 11. D.L.F. | 2½ yrs. | Oblique, long | Reduced | Plain double spica cast | 6½ | −2/16 | −2/16 | Normal |
| 12. E.W.W. | 2½ yrs. | Transverse, mid-third | End on, some anterior bow | Plain double spica cast | 9 | −3/16 | −3/16 | Slight anterior bow persists |
| 13. L.L.C. | 2½ yrs. | Spiral, upper third | Slight anterior angulation | Plain double spica cast | 9 | Even | 0 | Normal |
| 14. S.J.H. | 2½ yrs. | Oblique, mid-third | Reduced | Plain double spica cast | 15 | +4/16 | +4/16 | Normal |
| 15. J.A.F. | 2¾ yrs. | Oblique, mid-third | Reduced | Plain double spica cast | 8 | +2/16 | +2/16 | Normal |
| 16. J.F.J. | 3 yrs. | Transverse, subtrochanteric | End-on contact | Kirschner wire | 6 | +5/16 | +5/16 | Normal |
| 17. D.C. | 3 yrs. | Transverse, upper third | Length restored; little apposition | Plain double spica cast | 14 | Even | 0 | Slight valgus and anterior bow |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | third | | cast | | | | anterior bow |
| 19. | M.Mc. | 3 yrs. | Transverse, subtrochanteric | Anterior angulation | Plain double spica cast | 13 | +3/16 | +3/16 | 30 degrees anterior bow |
| 20. | B.L. | 3 yrs. | Oblique, mid-third | Slight overriding | Hoke traction | 21 | Even | 0 | Normal |
| 21. | J.W.D. | 3 yrs. | Mid-third | Slight overriding | Plain double spica cast | 7 | +3/16 | +3/16 | Normal |
| 22. | A.K.D. | 3 yrs. | Oblique, mid-third | Reduced | Kirschner wire | 5½ | +4/16 | +4/16 | Normal |
| 23. | N.E.E. | 4 yrs. | Oblique, upper third | Reduced | Plain double spica cast | 9 | Even | 0 | Normal |
| 24. | R.L.C. | 4 yrs. | Oblique, upper third | Reduced | Plain double spica cast | 7 | +3/16 | +3/16 | Normal |
| 25. | J.E.S. | 4 yrs. | Mid-third | Slight varus | Hoke traction | 20 | +4/16 | +4/16 | Shaft normal; bilateral flattened heads (cyst opposite femur) |
| 26. | S.F. | 4 yrs. | Transverse, lower third | Slight overriding distal end and proximal fragment anteriorly (remanipulated, 2 weeks) | Plain double spica cast | 15 | +9/16 | +9/16 | Normal |
| 27. | J.C. | 4 yrs. | Oblique, mid-third | Slight overriding | Plain double spica cast | 12 | +3/16 | +3/16 | Slight anterior bow |
| 28. | E.D.K. | 4 yrs. | Transverse, upper third | Slight valgus, no apposition | Kirschner wire | 5 | +8/16 | +8/16 | Slight valgus, shaft wider |
| 29. | M.P.S. | 5 yrs. | Oblique, subtrochanteric | 1/2 in. overriding | Plain double spica cast | 8 | −2/16 | +6/16 | Normal |
| 30. | A.E.S. | 5 yrs. | Oblique, mid-third | 5/16 in. overriding | Plain double spica cast | 11 | −2/16 | +3/16 | Normal |
| 31. | C.J. | 6 yrs. | Spiral, oblique | Reduced | Plain double spica cast | 17 | +4/16 | +4/16 | Normal |
| 32. | J.H.S. | 7 yrs. | Transverse, mid-third | Reduced | Plain double spica cast | 19 | Even | 0 | Normal |
| 33. | S.J.H. | 7 yrs. | Mid-third | Length all right, no engagement | Plain double spica cast | 19 | Even | 0 | Normal |
| 34. | H.J. | 7 yrs. | Mid-third | Overriding, 1 cm. | Plain double spica cast | 16 | −2/16 | +5/16 | Normal |
| 35. | R.W. | 7 yrs. | Mid-third | 12/16 in. shortening | Plain double spica cast | 20 | Even | +12/16 | Normal |
| 36. | M.C. | 7 yrs. | Subtrochanteric | Not known | Plain double spica cast | 21 | −5/16 | Not known | Normal |

TABLE I—*Continued*

| Case | Age at Time of Injury | Type of Fracture | Result of Manipulation | Type of Treatment | Age at Last Examination (*Years*) | Relative Length of Affected and Unaffected Limbs at Last Examination (*Inches*) | Gain or Loss in Length at Last Examination as Compared with Length at Cast Removal (*Inches*) | X-ray Contour |
|---|---|---|---|---|---|---|---|---|
| 37. A.R.T. | 7 yrs. | Transverse, mid-third | End on | Kirschner wire | 8 | +1/16 | +1/16 | Normal |
| 38. A.U. | 7 yrs. | Oblique, mid-third | 4/16 in. overriding, slight valgus | Kirschner wire | 10 | −3/16 | +1/16 | Slight valgus |
| 39. J.R.S. | 8 yrs. | Spiral, upper third | Slight anterior bow | Plain double spica cast | 14 | −4/16 | −4/16 | Slight anterior bow |
| 40. J.G. | 8 yrs. | Oblique, mid-third | Almost restored | Kirschner wire (injury 8 days old) | 16 | +4/16 | +4/16 | Normal |
| 41. J.P. | 8 yrs. | Oblique, mid-third | Reduced | Plain double spica cast | 19 | −5/16 | 0 | Normal |
| 42. J.R. | 8 yrs. | Oblique, upper third | Minimum overriding | Kirschner wire | 14 | −1/16 | 0 | Slight anterior and medial bow |
| 43. B.G. | 9 yrs. | Spiral, mid-third | Reduced | Plain double spica cast | 13 | −2/16 | −2/16 | Slight anterior and medial bow |
| 44. L.R.L. | 9 yrs. | Transverse, upper third | Valgus, end on | Kirschner wire | 12 | +5/16 | +5/16 | Slight valgus |
| 45. H.C. | 10 yrs. | Comminuted, mid-third | Slight shortening | Plain double spica cast | 20 | −8/16 | ? loss | Slight varus, has improved from 11 degrees to 3 degrees |
| 46. H.J. | 10 yrs. | Transverse, mid-third | 1 cm. over-riding | Kirschner wire | 11<br>13 | −3/16 (1957) | Even | Slight anterior bow |
| 47. R.K. | 10 yrs. | Transverse, mid-third | Reduced | Plain double spica cast | 21 | Has multiple left femoral deformities as a result of osteogenesis imperfecta; shaft straight | | |
| 48. O.D.T. | 12 yrs. | Transverse, mid-third | 12/16 in. overlap | Plain double spica cast | 23 | −8/16 | +4/16 | Slight anterior angulation |
| 49. W.B.G. | 12 yrs. | Transverse, upper third | Length restored | Kirschner wire | 14 | Even | 0 | Old Perthes disease on right; lesser trochanter even |
| 50. K.Y.P. | 13 yrs. | Oblique, distal third | Reduced (refracture) | Plain double spica cast | 14 | −8/16 | −8/16 | Normal |
| 51. W.M.W. | 13 yrs. | Spiral, upper third | Slight anterior angulation | Kirschner wire | 15 | −2/16 | −2/16 | Slight anterior angulation |
| 52. J.E.W. | 13 yrs. | Oblique, mid-third | Good position | Plain double spica cast | 15 | Even | 0 | Normal |
| 53. K.R.E. | 14 yrs. | Subtrochanteric | Greenstick type | Kirschner wire | 16 | Even | 0 | Slight anterior bow |

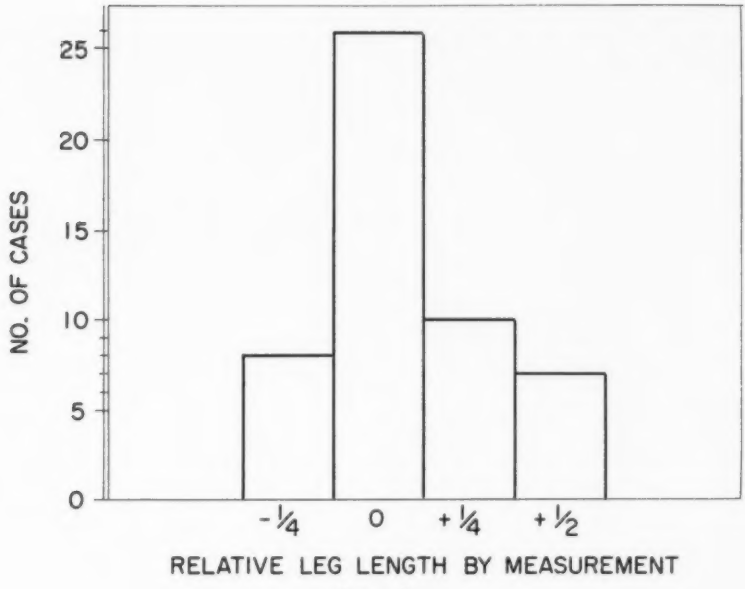


CHART I

Relative length, in inches, of the affected limb as compared with the unaffected limb. The measurements were made from the anterosuperior spine to the medial malleolus.

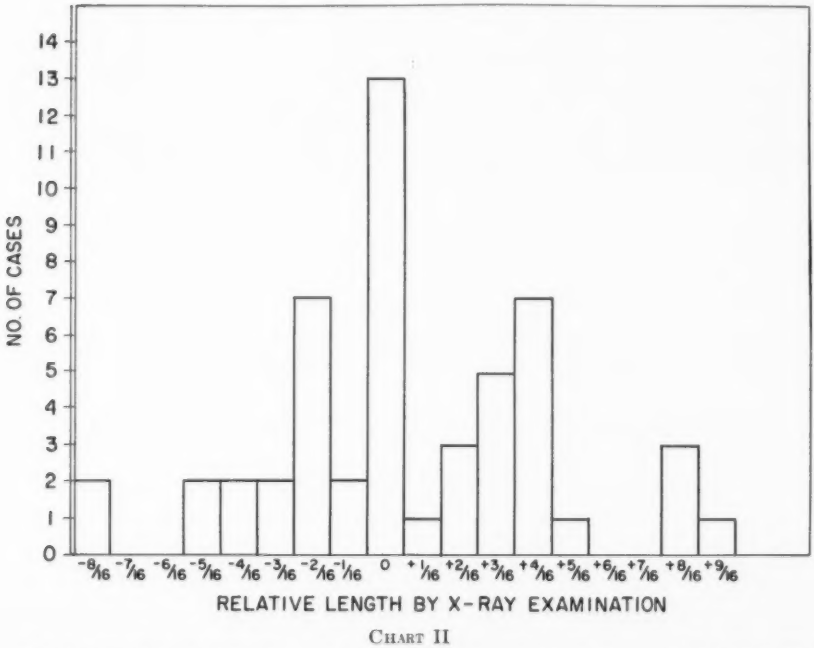


CHART II

Relative length, in inches, of the affected limb as compared with the unaffected limb. The measurements were made from standing roentgenograms.

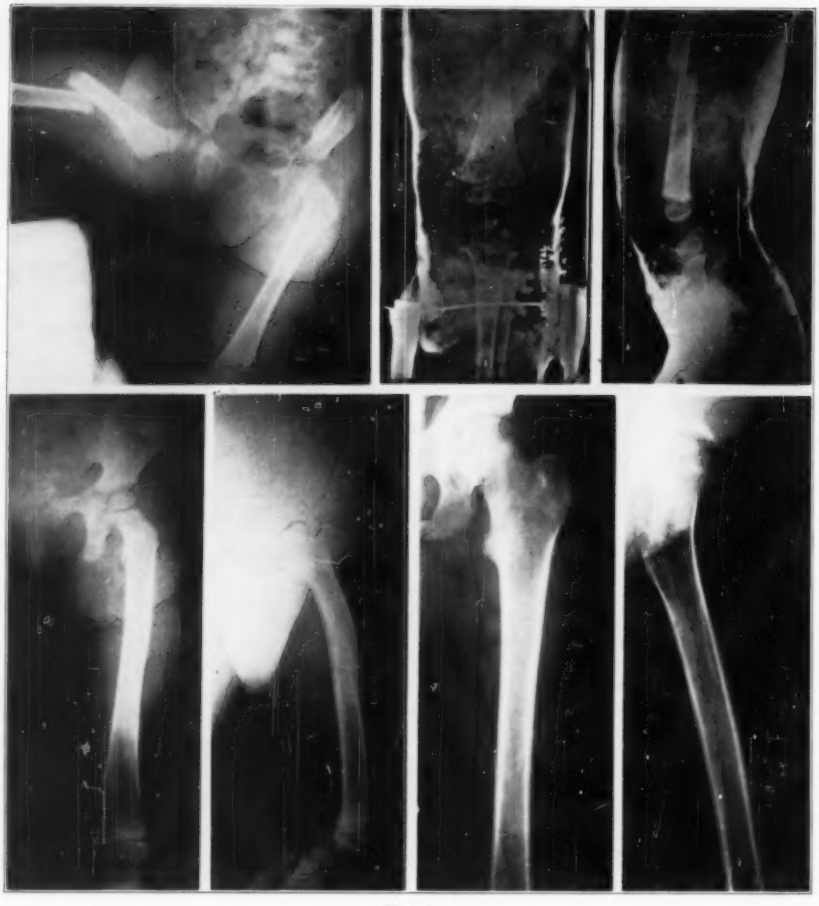

FIG. 5

Case 17. This three-year-old child had a transverse fracture at the junction of the middle and upper third of the femur, which was reduced with minimal contact of the fracture surfaces, but with good alignment. Roentgenograms made two years later showed only slight anterior bowing. A roentgenogram made at the time of this study, eleven years after injury, showed normal contour of the femur. The lengths of both femora were the same.

performed. There was no known deformity as an end result of a fracture [2]. There was one refracture which occurred three days after the cast was removed when the patient fell from a tree swing; a plaster-of-Paris double spica was applied for ten additional weeks, and the fracture healed without loss of function.

Fifty-three patients were re-examined one to twenty-two years after their fracture. The average follow-up interval was 6.9 years. In no patient was there any deformity, disturbance of gait, or limitation of knee or hip motion as a result of the injury. There were no symptoms, except for a few children in their early teens who had discomfort in the thigh in inclement weather and one patient who said that his injured leg tired more easily after climbing telephone poles.

The limb lengths were compared in each patient by measuring the distance from the anterosuperior spine to the medial malleolus of each limb (Chart I). None of the patients realized that they had any discrepancy of limb length before our examination.

### ROENTGENOGRAPHIC FOLLOW-UP

Anteroposterior and lateral roentgenograms of the affected femora were made of all patients in the follow-up study. It was observed that angulation at the fracture site sometimes, but not always, corrected itself in the ensuing years (Fig. 4). The contours of the femora that had been reduced with side-to-side apposition, but good alignment, in children under nine years of age were usually normal after three years (Fig. 5). There was no significant deformity remaining in any patient.

In order to compare limb lengths more accurately, a standing roentgenogram was made of the pelvis, including both hips. The distortion of the roentgenograms was determined by taping a ruler with calibrated metal markers at one-inch intervals over the greater trochanter before the roentgenograms were made (Chart II).

These scaled roentgenograms showed that at the time of the follow-up examination the limb that had been broken was an average of over one-sixteenth of an inch longer than the uninvolved limb. There were only four patients in whom the affected limb was more than one-quarter of an inch shorter than the unaffected limb, and five patients in whom the affected limb was more than one-quarter of an inch longer (Table I).

The amount of overriding (or distraction) at the time of union was not always accurately determinable. Hence, the relative growth of the affected limb could not be precisely compared with the unaffected limb. The original post-reduction roentgenogram or the measurement made from this roentgenogram by a roentgenologist was available in forty-seven of the cases. The basis for the determination of femoral growth was made from the roentgenograms at the time that the cast was removed. No comparison of length was made with the unaffected limb at this time (Table I, column 7).

It was apparent that all femoral-shaft fractures do not overgrow [1,2,3]. It is our impression from this series that transverse fractures in children under six years of age can be expected to overgrow. The amount of overgrowth, however, was not enough to be noticed by any of the patients with long follow-ups who were examined by us. There was little additional growth stimulus after oblique and spiral fractures or in fractures in children over eight years of age.

### DISCUSSION

Complications from femoral-shaft fractures in children, although not common, do occur. They are:

1. Malunion;
2. Volkmann's contracture and gangrene in the affected or non-affected limb when the feet are elevated, while the patient is in clinical or subclinical shock [8,10];
3. Delayed union from distraction or lack of immobilization is unusual;
4. Non-union is practically non-existent, except in patients who have had open reduction. Open reduction is mentioned only to condemn it as a method of treatment for femoral-shaft fractures in children. Therefore, its many complications shall not be listed.

None of these complications occurred in the patients in this series.

### COMMENT

Immobilization by a double plaster-of-Paris spica according to the method described gives excellent fixation for femoral-shaft fractures. It has obvious financial advantages for the patient's family since it reduces the hospital stay to one or two days. Once the fracture is reduced and the cast applied, there is no difficulty in maintaining proper position and alignment. Since there is very little movement of the limb within the cast, the Kirschner wire in the tibia does not cause irritation or infection. The one disadvantage of this method, in contrast to Bryant's or Russell's traction, is that it does require anesthesia. In suitable patients local anesthesia was used without difficulty. There were no complications in

this series as a result of the anesthesia. It was found that even when patients have to remain in the hospital their nursing care has been much easier. In our community there is a shortage of hospital beds and this method of treatment has been of great benefit in this regard. With younger children who are not toilet trained, precautions should be taken to prevent soiling of the cast by applying oiled silk or plastic material around the perineum.

## CONCLUSION

Early reduction and spica-cast immobilization can be expected to give excellent results in children with femoral-shaft fractures. There are other methods which also can give excellent results for this same type of fracture. The physician should decide which method he can safely administer to the best advantage of his patient. It is our opinion that early reduction and double spica plaster-of-Paris immobilization is a safe, certain, comfortable, and economical method of treatment.

## REFERENCES

1. Aitken, A. P.; Blackett, C. W.; and Cincotti, J. J.: Overgrowth of the Femoral Shaft Following Fracture in Childhood. J. Bone and Joint Surg., **21**: 334-338, Apr. 1939.
2. Blount, W. P.: Fractures in Children, pp. 129-145. Baltimore, The Williams and Wilkins Co., 1955.
3. Blount, W. P.; Schaefer, A. A.; and Fox, G. W.: Fractures of the Femur in Children. Southern Med. J., **37**: 481-493, 1944.
4. Campbell, W. C.: Fractures of the Shaft of the Femur. Radiology, **12**: 106-113, 1929.
5. Conwell, H. E.: Acute Fractures of the Shaft of the Femur in Children. A Report of the Treatment and Results Attained in Eighty-six Acute Fractures of the Shaft of the Femur in Eighty-five Children, with a Résumé of Various Types of Treatment and Results Attained by Other Surgeons. J. Bone and Joint Surg., **11**: 593-647, July 1929.
6. Firor, W. M.: The Use of Plaster in the Treatment of Fractured Femurs. Bull. Johns Hopkins Hosp., **35**: 412-415, 1924.
7. LeMesurier, A. B.: The Treatment of Fractures of the Shaft of the Femur in Children. Am. J. Surg., **49**: 140-146, 1940.
8. Miller, D. S.; Markin, Leo; and Grossman, Edward: Ischemic Fibrosis of the Lower Extremity in Children. Am. J. Surg., **84**: 317-322, 1952.
9. Moore, R. A., and Schafer, E. W.: Treatment of Simple Fractures of the Shaft of the Femur by a Fixed Traction Spica. A Preliminary Report. North Carolina Med. J., **9**: 514-519, 1948.
10. Robinson, R. A.: Personal communication.
11. Scudder, C. L.: The Treatment of Fractures. Ed. 10, pp. 591-600. Philadelphia, W. B. Saunders Co., 1926.

# Arthrography in the Diagnosis of Meniscal Injuries of the Knee

## A Correlation of the Roentgenographic, Clinical, and Operative Findings*

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Many articles on arthrography of the knee have appeared in the medical literature since the procedure was first described by Werndorff and Robinsohn in 1905. Numerous reports on arthrography appeared in the decade from 1942 to 1952, but few have appeared since that time.

Despite the need for greater accuracy in the diagnosis of those conditions usually referred to by the catch-all term, internal derangement of the knee, and despite claims that arthrography aids materially in making an exact anatomical diagnosis, there are still many orthopaedic surgeons and many roentgenologists in this country who do not use this method. Two reasons for this are the difficulty in learning to interpret the films correctly and the time and expense involved.

It is particularly desirable to have an aid to accurate diagnosis of those patients who continue to complain of symptoms, but whose history and physical findings are either atypical or only suggestive of tear of the meniscus.

Because arthrographic examinations of the knee promised to increase the accuracy of diagnosis, one of us (FBW), a roentgenologist, studied the method with Knut Lindblom, in 1950, and, in the process, the arthrograms of nearly 500 patients were compared with the pathological condition reported at operation.

Since then we have performed arthrographic examinations, using a water-soluble contrast medium, in 469 patients in our hospital, and this paper is a report on this experience.

### LITERATURE

The literature contains widely differing reports on the accuracy of diagnosis by arthrography (Table I). The accuracy of correct diagnoses varies from 53 per cent to nearly 100 per cent.

Jensen and Andersen in a series of thirty-eight cases submitted to surgery obtained the correct diagnosis in twenty (53 per cent); in the remaining eighteen cases arthrography was either technically unsatisfactory or the diagnosis by this method was uncertain or incorrect.

McGaw and Weckesser, in studying the pathology in 101 operations on the knee, found (1) that pneumarthrography was a "conclusive diagnostic aid" in forty-three, that is, the preoperative roentgenographic diagnosis was correct, whereas the clinical diagnosis was incorrect and (2) that it was a "limited diagnostic aid" in forty, that is, confirming the correct clinical diagnosis. Altogether, the diagnosis by arthrography was correct in 82 per cent; unsatisfactory for technical reasons in 15 per cent; and misleading or contradictory in 3 per cent.

Sachs, McGaw, and Rizzo achieved an accuracy of 86.5 per cent in fifty-two cases proved at surgery. In an additional 3.9 per cent, the diagnosis was partially correct; in 5.7 per cent, the diagnosis was wholly incorrect; and in 3.9 per cent, the examination was unsatisfactory.

Somerville reported on one of the largest series in the literature, including

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TABLE I

ACCURACY OF DIAGNOSIS BY ARTHROGRAPHY

| Author | Year | No. of Cases | Correct Diagnosis (*Per cent*) |
|---|---|---|---|
| Jensen and Andersen | 1952 | 38 | 53 |
| Sevastikoglou | 1954 | | 58 |
| Keats, Staatz, and Bailey | 1952 | 80 | 75 |
| McGaw and Weckesser | 1945 | 101 | 82 |
| Sachs, McGaw, and Rizzo | 1950 | 52 | 86.5 |
| Kjeld Andersen | 1948 | 75 | 91 |
| Somerville | 1946 | 205 | 94 |
| Lindblom | 1948 | | 95 |
| Stack and Lockwood | 1951 | 144 | 95.3 |

TABLE II

ACCURACY OF CLINICAL PREOPERATIVE DIAGNOSIS

| Author | Year | No. of Cases | Correct Diagnosis (*Per cent*) |
|---|---|---|---|
| Jensen and Andersen | 1952 | 38 | 50 |
| Sachs, McGaw, and Rizzo | 1950 | 159 | 70 |
| Keats, Staatz, and Bailey | 1952 | 80 | 70 |
| Stack and Lockwood | 1951 | 107 | 70 |
| Kjeld Andersen | 1948 | | 89* |
| Bonnin and Boldero | 1947 | 49 | 92 |

* Highly selected series of typical cases.

205 knees on which operation was performed after arthrography. In 195 (94 per cent) the roentgenographic diagnosis was correct.

Lindblom stated that the diagnosis of rupture of the meniscus (by contrast arthrography) was 95 per cent accurate. He did not state how many cases were proved at surgery, but did say that knee arthrography had been performed in more than 4,000 cases.

Reports of the accuracy of clinical preoperative diagnosis also vary widely (Table II).

McGaw and Weckesser graded the preoperative diagnosis in 101 cases; 37 per cent were entirely correct, 42 per cent partially correct, and in 21 per cent, the diagnosis was misleading.

In a careful study of thirty-eight cases, Jensen and Andersen found that twenty-one had the history and findings quite typical of a ruptured meniscus; in nineteen of these the diagnosis was confirmed at operation, but in two the menisci were found to be normal. In nine patients in whom the signs and symptoms were "marked, but not typical" of injury to the meniscus, eight were found to have a pathological condition of the meniscus. In the eight patients in whom the clinical findings were atypical, four were found to have torn menisci, and in four, findings were negative on exploration.

Stack and Lockwood achieved a correct clinical and pneumarthrographic diagnosis in seventy-five (70 per cent) of 107 cases. Bonnin and Boldero were accurate in 92 per cent of forty-nine cases.

Undoubtedly, the accuracy of the clinical diagnosis of injury to the meniscus depends on the experience of the surgeon and other factors, but in every series there will be a sizable proportion of cases in which the pathology is obscure, and the symptoms and findings atypical, or, at best, only suggestive. It is in these cases that an ancillary method of examination could prove of great value.

## METHOD OF ARTHROGRAPHY

Contrast arthrography, using 35 per cent diodrast solution, was the method employed. Air arthrography probably offers some advantages in the roentgenographic diagnosis of lesions other than meniscal—arthritis, synovitis, or osteochondritis dissecans—although some non-meniscal pathological conditions, such as cartilaginous loose bodies and osteocartilaginous fractures, may show up more clearly with opaque contrast than with gas arthrography. In any case, the method in which an opaque contrast medium is used is not at a disadvantage in the diagnosis of lesions of the menisci, and it is these structures with which we are most concerned. The diagnosis of non-meniscal injuries can usually be made on the basis of the clinical findings, history, and regular roentgenographic examination.

The diodrast solution is miscible with the joint fluid, and, unlike air, can be used in the presence of joint effusion.

FIG. 1

Arthrogram. The radiopaque diodrast coats the surface of the articular cartilage of the tibia and of the femur and the surface of the menisci. Some of the diodrast has seeped down into a vertical rent in the posterior third of the medial meniscus. If all tears of the meniscus were demonstrated as clearly as in this arthrogram, interpretation would be easy.

## TECHNIQUE

Great care is used to clean the skin as carefully as for any surgery; the leg is shaved, washed for ten minutes with surgical soap, and treated with ether, alcohol, and zephiran chloride solution before draping with sterile sheets. The procedure is done in the roentgenology department by the roentgenologist, who is suitably attired in cap, mask, sterile gown, and gloves.

The knee joint is entered through the lateral extension of the quadriceps tendon just proximal to the patella itself so that the tip of the needle cannot damage the articular cartilage of the patella or femur. The amount injected into the joint varies from ten to fifteen cubic centimeters, the larger amount being used in large persons and in knees which are tightly distended with joint fluid. The joint fluid is always aspirated, prior to the injection of diodrast solution, when patellar ballottement is present. An elastic bandage is applied tightly about the knee, immediately after removal of the needle. The bandage forces the solution out of the quadriceps pouch and onto the meniscal surfaces. It is removed before making the lateral roentgenograms to permit roentgenographic visualization of the quadriceps pouch. When, on occasion, diodrast was injected into the tissues rather than into the joint, the area became acutely painful and remained so for several hours; no other complication ensued. Diodrast is rather

quickly absorbed and excreted through the kidneys; it disappears from the joint and the soft tissues within a matter of hours. No complications resulted from arthrography in this series, with the exception just noted.

The examination is expensive from the point of view of time needed by a technician and roentgenologist, as well as the use of sterile supplies and an x-ray room for thirty to forty-five minutes. Twelve roentgenograms (six stereoscopic views, as recommended by Lindblom) are obtained, as well as the routine views of the standard roentgenographic examination of the knee.

The interpretation of the roentgenograms is also time consuming. It is essential to have a roentgenologist who is interested and willing to spend the amount of time necessary, not only to perform and interpret the examination, but also to check and recheck his interpretation with the pathological condition found at surgery, so that both he and the surgeon can build up confidence in the roentgenographic diagnosis of lesions of the meniscus.

The amount of radiation exposure to the patient is a matter of concern. In our department, the exposure to the skin of the knee for the full examination has been calculated at 140 milliroentgens on the lateral aspect, and 700 on the anterior aspect. We have not attempted to measure the dose to the gonads, but this has been done elsewhere [13]; with techniques similar to ours, the dose to the testes was 6.5 milliroentgens and to the ovaries, between one and two milliroentgens.

## CONTRA-INDICATIONS

No absolute contra-indications to arthrography have been noted, save the obvious one of infection in or around the joint.

There are, however, several situations in which the examination seldom gives satisfactory information of the state of the menisci. If marked degenerative arthritis is present, as disclosed by standard roentgenograms, arthrograms are difficult to interpret. A satisfactory examination cannot be done if the knee cannot be extended to at least 170 degrees. This block occurs in a bucket-handle tear of the meniscus when the handle slips into the intercondylar notch, preventing full extension.

Fortunately, in these two situations, the diagnosis is usually quite apparent from clinical observation alone.

Arthrography should not be attempted in children because they are unable to cooperate and to lie still during the examination. Incidentally, the youngest patient in this series was a boy of five who had a large cyst of the lateral meniscus and a complete vertical tear of the discoid lateral meniscus. Arthrography was not attempted in this patient.

## MATERIAL

During the period of this study (1951 to 1958) 318 operations for internal derangement of the knee were done on 298 patients. A total of eighty-seven operations were done for such conditions as osteocartilaginous loose bodies, osteochondritis dissecans, synovitis, ligamentous injury, chondromalacia of the patella and other conditions in which the pathological condition involved structures other than the menisci. These cases were not included in this analysis, which is concerned with the accuracy of this procedure in the diagnosis of tears of the meniscus. In forty-three instances arthrography was not done, usually because the patient had a painful, locked knee and a history and physical findings perfectly typical of a tear of the meniscus with displacement. This leaves a group of 188 cases for analysis.

The question of how to classify the loose meniscus and hypertrophy of the infrapatellar fat pad is a troublesome one. Both diagnoses are so inexact and subject to such variation in interpretation that we have chosen to designate them, at least for the purpose of this discussion, as negative explorations.

### DIAGNOSIS BY ARTHROGRAM

The diagnosis by arthrograms was correct in 136 cases (73 per cent). Of the fifty-two times that errors were made in interpretation of the roentgenograms seventeen were errors of commission, that is, we thought there was damage to a meniscus when, in fact, none could be found at operation.

*Medial Meniscus*

In fifty knees where the history and findings were typical of a tear of the medial meniscus, the diagnosis was correct in forty-five (90 per cent). In seventy-six with a suggestive clinical picture, the diagnosis was correct in fifty-eight (76 per cent). In twenty-nine with an atypical clinical picture, the diagnosis was correct in twenty-one (72 per cent). The arthrograms corresponded to the findings at surgery 124 times in 155 arthrotomies. Thus, the over-all accuracy in injuries of the medial meniscus is 80 per cent.

*Lateral Meniscus*

A quite different result occurs when the figures for the roentgenographic diagnosis of tears of the lateral meniscus are analyzed. Tears of the lateral meniscus were found forty-two times at surgery. The diagnosis was made by arthrography in only twelve (30 per cent). In nine instances with typical history and physical findings, the roentgenographic examination was correct seven times (78 per cent). In thirteen with suggestive clinical pictures, the diagnosis was correct only two times (15 per cent); and in eleven cases with an atypical clinical picture, the roentgenographic examination was correct in three (27 per cent).

*Both Menisci*

In none of the seven patients in whom tears of both menisci were found was the diagnosis of tear of the lateral meniscus made by roentgenogram.

In two instances the history and physical findings were suggestive of injury to the lateral meniscus only. Arthrography showed a tear in the posterior aspect of the medial meniscus. In both instances the medial meniscus was removed on the basis of the arthrogram, and the diagnosis of posterior tear was confirmed. Had only the usual lateral approach for the torn lateral meniscus been made, the lesion of the medial joint would have escaped attention.

In three instances the history and findings suggested tears of the medial meniscus; arthrography confirmed this impression in one, and was not done in the other two. The tear of the lateral meniscus in each of these patients was discovered at surgery.

In two instances with an atypical clinical picture, arthrography revealed a tear in the medial meniscus which was confirmed at surgery, whereas the tear of the lateral meniscus was discovered at surgery.

In no instance did the arthrogram indicate a diagnosis of lesions in both menisci.

### CLINICAL DIAGNOSIS

In the analysis of the accuracy of the clinical diagnosis of injuries of the menisci, a total of 259 arthrotomies was available. A lesion was found in the medial meniscus in 217; in the lateral meniscus in thirty-five; and in both the medial and lateral menisci in seven. The ratio of injury of the medial meniscus to injury of the lateral meniscus is six to one.

*Medial Meniscus*

Arthrotomy was done eighty-eight times when the history and physical findings were typical of those associated with injury to the medial meniscus. In eighty of these, the pathological condition at operation was found to involve the medial meniscus (90 per cent).

In eighty-nine instances in which the history and findings were not exactly typical but nonetheless strongly suggestive, a pathological condition was found in the medial meniscus seventy-two times (80 per cent). In forty-eight instances in which the history and findings were atypical, the medial meniscus was found to be injured in twenty-eight (58 per cent) and normal in twenty (42 per cent).

*Lateral Meniscus*

In forty-two arthrotomies, the lesion was found in the lateral meniscus.

In twelve of these with typical histories and physical findings, involvement of the lateral meniscus was found in all but one. In seventeen explorations where the history and physical findings were only suggestive, a pathological condition of the lateral meniscus was also found in all but one. In the remaining thirteen arthrotomies, involvement of the lateral meniscus was found, even though the history and findings did not suggest an injury here.

*Both Menisci*

A pathological condition was found in both menisci in seven patients. In no instances were both lesions diagnosed clinically, prior to surgery.

## DISCUSSION

In common with all other series reported in the literature, no consideration has been given to those cases in which arthrography was done but surgery was not, although the inclusion of these cases conceivably might alter our impression, to a marked degree, of the accuracy of arthrography. In almost all of these instances the arthrograms were read as negative. This failure to take into account those cases which cannot be submitted to proof is a factor which is present in almost all clinical medical research and which vitiates, to a degree, the statistics put forth.

In analyzing these results, we have recorded the accuracy of the clinical diagnosis in percentages. This is, however, somewhat misleading. For example, in lesions involving the medial meniscus with an atypical clinical picture, the diagnoses are recorded as being correct in twenty-eight out of forty-eight. This does not mean, however, that our clinical diagnosis was accurate in 58 per cent, for about the best that we were able to do in these cases was to recommend an exploratory operation, since injury to the medial meniscus was one, and possibly the most likely, of several possibilities. Similarly, it should be noted that in all thirteen of the patients with atypical history and physical findings in whom a tear of the lateral meniscus was found at operation, this diagnosis was not made preoperatively.

It becomes apparent, then, that examination by arthrogram is of value in meniscal injuries where the clinical picture is atypical or suggestive. The diagnosis of a tear of the medial meniscus was as accurate by roentgenogram as by clinical impression in those patients with a suggestive history and physical examination, and was more accurate in the atypical cases.

In many arthrotomies the medial meniscus appeared normal on inspection through the usual anterior approach, but was nevertheless removed because of the roentgenographic diagnosis of a posterior tear; at removal the roentgenographic diagnosis was confirmed in seventeen instances.

## CONCLUSIONS

Arthrography of the knee is of value in the diagnosis of lesions of the medial meniscus, particularly in those patients in whom the history and physical findings are atypical or only suggestive.

In the patient who presents himself with a locked knee and the typical history and findings of tear of the meniscus with displacement, arthrography is neither necessary nor helpful.

The value of arthrography in the diagnosis of lesions of the lateral meniscus is doubtful.

It is necessary to understand the fallibility of this ancillary method of diagnosis in order to use it intelligently. In common with most laboratory examinations, both false-positive and false-negative findings can be read. The mistaken negative examination is more prevalent than the mistaken positive.

The procedure is time consuming and, therefore, expensive from the standpoint of the roentgenology department and requires experience in interpretation.

## REFERENCES


1. Andersen, Kjeld: Pneumoarthrography of the Knee Joint. With Particular Reference to the Semilunar Cartilages. Acta Orthop. Scandinavica, Supplementum 4, 1948.
2. Bonnin, J. G., and Boldero, J. L.: Air Arthrography of the Knee Joint. Surg., Gynec., and Obstet., **85:** 64-70, 1947.
3. Borow, L. S.: Arthrography. II. The Evaluation of Pneumoarthrography. British J. Radiol., **25:** 129-134, 1952.
4. DePalma, A. F.: Diseases of the Knee. Management in Medicine and Surgery. Philadelphia, J. B. Lippincott Co., 1954.
5. Fuiks, D. M., and Grayson, C. E.: Vacuum Pneumarthrography and the Spontaneous Occurrence of Gas in the Joint Spaces. J. Bone and Joint Surg., **32-A:** 933-938, Oct. 1950.
6. Geist, R. M., Jr.; Whitsett, C. C.; and Hughes, C. R.: Diodrast Arthrography of Knee. Cleveland Clin. Quart., **18:** 231-236, 1951.
7. Hauch, P. P.: Arthrography. I. A Comparative Study of Arthrography of the Knee Joint. British J. Radiol., **25:** 120-129, 1952.
8. Hickman, E. A.: Pneumoarthrography. J. Nat. Med. Assn., **47:** 25-29, 1955.
9. Jensen, S. B., and Andersen, P. T.: Arthrography as a Diagnostic Aid in Lesions of the Knee Joint. Acta Chir. Scandinavica, **103:** 302-305, 1952.
10. Jowett, A. E.: Opaque Arthrography of the Knee Joint. Ann. Rheumat. Dis., **8:** 149-155, 1949.
11. Klami, P., and Kurkipää, M.: Tomoarthrography of Meniscal Lesions of the Knee-Joint. Fifteen Verified Cases. Acta Radiol., **48:** 248-256, 1957.
12. Keats, T. E.; Staatz, D. S.; and Bailey, R. W.: Pneumoarthrography of Knee. Surg., Gynec., and Obstet.: **94:** 361-364, 1952.
13. Larsson, Lars-Eric: Radiation Doses to the Gonads of Patients in Swedish Roentgen Diagnostics. Studies on Magnitude and Variation of the Gonad Doses Together with Dose Reducing Measures. Acta Radiol., Supplementum 157, 1958.
14. Lindblom, Knut: Arthrography of the Knee. A Roentgenographic and Anatomical Study. Acta Radiol., Supplementum 74, 1948.
15. McGaw, W. H., and Weckesser, E. C.: Pneumarthrograms of the Knee. A Diagnostic Aid in Internal Derangements. J. Bone and Joint Surg., **27:** 432-445, July 1945.
16. Meschan, Isadore, and McGaw, W. H.: Newer Methods of Pneumoarthrography of the Knee with an Evaluation of the Procedure in 315 Operated Cases. Radiology, **49:** 675-711, 1947.
17. Murray, R. C., and Forrai, Elemér: Transitory Eosinophilia Localised in the Knee Joint after Pneumarthrography. J. Bone and Joint Surg., **32-B:** 74-83, Feb. 1950.
18. Palmer, Ivar: On the Injuries to the Ligaments of the Knee Joint. A Clinical Study. Acta Chir. Scandinavica, Supplementum 53, 1938.
19. Sachs, M. D.; McGaw, W. H.; and Rizzo, R. P.: Studies in the Scope of Pneumoarthrography of the Knee as a Diagnostic Aid. Radiology, **54:** 10-32, 1950.
20. Sevastikoglou, John: Cited by Klami and Kurkipää.
21. Smillie, I. S.: Injuries of the Knee Joint. Ed. 2. Baltimore, William and Wilkins Co., 1951.
22. Somerville, E. W.: Air Arthrography as an Aid to Diagnosis of Lesions of the Menisci of the Knee Joint. J. Bone and Joint Surg., **28:** 451-465, July 1946.
23. Stack, J. K., and Lockwood, R. C.: Pneumoarthrograms of the Knee. An Aid in the Localization of Internal Derangement. A.M.A. Arch. Surg., **63:** 486-495, 1951.
24. Werndorff, R., and Robinsohn, I.: Über intraarticulare und interstitielle Sauerstoffinsufflation zu radiologischen, diagnostischen und therapeutischen Zwecken. Presented before the German Society for Orthopaedic Surgery, Fourth Congress, 1905.


Note: The authors are grateful to their colleagues in the Orthopaedic Department of the Evanston Hospital for permission to include their cases in this study.

## DISCUSSION

Dr. J. I. Kendrick, Cleveland, Ohio: In 1952, I became interested in arthrography and decided to examine injured knees, using diodrast as the contrast medium. I discussed the project with Dr. Greenwald and Dr. Meany of our x-ray department, and they agreed to study the roentgenograms with me and by so doing to develop skill in interpreting them.

There are many recesses in the knee in which the dye can collect, and I think inaccuracy in interpreting the films, rather than fault of the method, is a frequent cause of error. Since the paper of Dr. Turner and Dr. Wurtz is also a statistical one, I got out all of the records of my patients who had had operations for injuries to the cartilage so that I could compare my results with those of the authors.

Because there were only fifty-four cases, I could not analyze them in all the categories presented by the authors. There were twenty-nine patients who had not had arthrograms, and twenty-five who had. For comparison, I checked the accuracy of the clinical diagnosis in the twenty-nine patients who did not have arthrograms. All of these patients had histories of injury and locking or instability. The diagnosis of a torn cartilage seemed to be clear. In twenty-four cases a diagnosis of torn medial semilunar cartilage was made. In nineteen of this number (79 per cent) the diagnosis was confirmed at operation and in five (21 per cent), the diagnosis was incorrect. There were five cases in which the diagnosis of a torn lateral cartilage was made and in all of these cases the diagnosis was confirmed at operation. The small number makes this group of no statistical significance.

Our method of carrying out the arthrogram was identical with the technique presented by the authors. We used eight to twelve cubic centimeters of 35 per cent diodrast. The eight cubic centimeters seemed to be adequate in most cases, and we did not find that diodrast irritated the joint.

There was one patient who seemed to have more pain, but the synovial biopsy done the day after arthrography at operation, showed no evidence of acute inflammation. Synovial biopsies done twenty-four hours after arthrography in most cases were studied; these revealed either no diagnostic findings or mild chronic inflammation. We had no infections as a result of the examination.

Early in our series we made many more roentgenograms, but finally settled on six and seemed to get along as well with this number as with more.

I can agree completely with the authors that there are no contra-indications to the procedure, other than infection around the joint, and that the morbidity is minimal. Of the twenty-five patients who had arthrograms, the diagnosis was not entirely clear or they would not have been subjected to the examination. In comparing results with the 79 per cent accuracy in the clinical diagnostic group, this factor should be taken into account. Of the twenty-five patients, eighteen had injuries of the medial cartilage. Of the eighteen, sixteen gave a history of some type of injury—from either squatting or bumping the knee, but not necessarily from twisting. There was no history of an injury in two.

The arthrograms were correct in fifteen cases (83 per cent), as confirmed at operation. The arthrograms were incorrect in three cases (17 per cent), as confirmed at operation. Of the seven cases of injury of the lateral cartilage, studied by arthrography, six gave a history of some type of injury and one, of no significant trauma. The diagnosis in the arthrogram was correct in five (71 per cent), and incorrect in two (29 per cent), as confirmed at operation.

In summarizing, I find little with which to disagree. My personal experience in this type of arthrography has convinced me of its value in the suggestive and atypical cases. I, too, have found that false-negative examination is more frequent than the false-positive. The arthrogram is a relatively painless procedure and without harmful sequelae. I have had the same experience as the authors of injecting a small amount of dye into the soft tissues; there was only slight immediate pain and fleeting soreness. The dyes absorb from the joint rather rapidly, and unless the roentgenograms are completed within thirty minutes, the contrast is poor.

It was my initial impression that in the typical cases the clinical diagnosis should be accurate in 90 per cent; the 80 per cent accuracy in my clinical cases, I think, is low, and the 90 per cent arrived at by the authors in typical cases is more representative.

The services of a good technician to make the roentgenograms and the help of a roentgenologist experienced in reading them determine the accuracy and usefulness of this procedure. On this point, the authors bring emphasis and I strongly agree.

DR. WURTZ (closing): I was a little dismayed at the comparison of our statistics for accuracy in the interpretation of these arthrograms with those of other workers. It would sound noble and scientific to say that this is probably because we are not very adept at the interpretation. However, I am not convinced that this is the case. We have had a number of patients with technically perfect arthrograms which appeared to show normal findings; the patients were later shown to have gross tears of the menisci. Even in retrospect, these tears cannot be seen on the arthrograms.

I do think it is important not to attempt interpretation of the arthrogram unless it is technically perfect. In order to ensure this perfection as often as possible the following points should be made with respect to the technique:

1. A physician should position the patient for the roentgenograms; if this is delegated to a technician it should be to one who understands the problems involved and who always performs the examination.

2. There is little value to be obtained in performing arthrography of this type in patients whose knees are locked or in those who have degenerative arthritis. The resulting examination is not very informative.

3. Any fluid which is in the joint at the beginning of the examination should be aspirated as completely as possible.

4. The knee must be vigorously moved through its entire range of motion after the introduction of the opaque material.

# The Effects Produced in the Cartilaginous Epiphyseal Plate of Immature Dogs by Experimental Surgical Traumata*†

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For over two hundred years the epiphyseal plates of the long bones have claimed the attention of many investigators.

Hales in 1727, du Hamel in 1743, and Hunter in 1760 showed that the longitudinal growth of the long bones occurs at the ends. These workers and subsequent experimenters demonstrated the existence of this growth by placing markers in the bone [4,11,17,22,30,50,61,66], by feeding madder which is selectively fixed in those portions of the skeleton which are growing [2,29,35,40,51], and by following the course of the lines of growth arrest [5,7,8,12,18,39,52,59,68].

The microscopic anatomy of the epiphyseal plate was first described in 1858 by Müller and clarified by Fell, Ham, Streeter, and others [10,42,46,47]. Starting at the epiphyseal margin of the plate, these investigators described zones of resting cartilage, proliferating cartilage, maturing and hypertrophic cartilage, and calcified cartilage. Leser, Retzius, and others [11,42,54,63] believed that the interstitial growth of the epiphyseal plate was caused by increase in the size of individual cartilage cells as they mature, and by active proliferation of the cartilage cells in the zones of the plate nearest the epiphysis where the existence of mitoses was noted.

Some clinical and experimental findings might seem to indicate that part of the growth in length of a long bone or a bone graft is due to interstitial growth within the bone itself. An increase in the length of the mass of a spine fusion has been noted in immature animals [4,41] and in children [26,45,56]. Odelberg-Johnson and Lacroix have attempted to explain this apparent increase in length on the basis of small infractions with subsequent healing. Selye and Hellstadius, in experimental studies on very young animals, interpreted new-bone formation at the distal tip of the femur after extirpation of the epiphysis as intrinsic growth of the bone, although their illustrations suggest ectopic-bone formation. Despite these opinions to the contrary, the weight of experimental evidence supports the basic concept that interstitial growth of cartilage within the epiphyseal plates accounts for the growth force which causes the elongation of growing long bones.

The effects of injury to the epiphyseal plate caused by surgically produced defects or incisions have been observed clinically and in experimental investigations. Ollier, in 1867, showed that superficial linear incisions across the epiphyseal plates in rabbits and cats often caused no disturbance of growth, whereas deep incisions caused retardation. Similarly, multiple punctures of the plate using needles did not affect growth. Vogt, in 1873, did not find any retardation of growth if epiphyseal separation was produced through the natural line of cleavage in the epiphyseal plates of goats and sheep except when the epiphysis was deeply lacerated at the time of separation. Jahn, in 1892, noted that in rabbits,

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if transversely oriented discs of epiphyseal plate, 0.5 to one millimeter in diameter, were removed from the zone of the plate at the epiphyseal end of the cartilage columns, these columns were unable to reproduce themselves. Haas, in 1917 and 1919, carefully analyzed the growth disturbance in the metacarpal and metatarsal bones of dogs produced by surgical incisions, crushing injuries, and curettement of the center of the epiphyseal plate. Gatewood and Banks noted that growth disturbance occurred after experimental damage to the epiphysis only if the epiphyseal plate itself was damaged. Imbert and Ford showed that if holes of small gauge were drilled across the plate from the epiphysis into the metaphysis little, if any, growth retardation occurred, whereas holes of large gauge caused marked retardation. Complete destruction of either the periphery or the center of the plate caused arrest of growth. Deformities resulted when defects were eccentrically placed. Phemister, in 1933, by clinical observation, based his operative arrestment of longitudinal growth on similar principles by making defects in the epiphyseal plate and filling them with cancellous bone. Siffert and others [6,15,16] showed in rabbits that defects produced in the epiphyseal plates did not heal by proliferation of the cartilage at the epiphyseal plate; on the contrary, they were repaired by bone. In those instances where focal injuries to the epiphyseal plate did not cause a complete arrest, a localized "dip" in the epiphyseal plate, which extended into the metaphysis, developed at the point of injury. Such pathological changes were similar to those described by Ross and Sissons in cases of growth retardation after prolonged immobilization of the lower extremity. After creating defects in the lateral half of the distal femoral epiphyseal plate in rabbits, Friedenberg failed to decrease the resulting progressive deformity by resecting the osseous bridge which formed between the epiphysis and metaphysis and filling the defect with wax or methyl methacrylate. Although growth disturbance has been shown to follow the formation of a bone bridge between the epiphysis and the metaphysis in animal experiments and in the Phemister growth-arrest operation, Hatt, in 1940, stated that cortical-bone grafts crossing the central portion of the epiphyseal plate in children did not cause arrest of growth.

The results of injury to the cartilaginous epiphyseal plate by penetrating wires, nails, and screws have been observed in both immature experimental animals and in children. Haas [23] showed that in immature dogs some growth retardation was caused by placing a smooth nail or wire through the central portion of the plate. The amount of growth disturbance caused by this procedure was not uniform, and Haas believed that this lack of uniformity was caused by variations in the firmness of fixation obtained. When two oblique pins were used the retardation was greater. Green and Cohen stated that in rabbits no retardation of growth occurred in their experiments if a smooth pin of small gauge was used, whereas arrest did follow the use of a screw. They believed that this arrest was the result of the firm anchorage of the screw on both sides of the plate. Imbert, Ford, and Siffert found that little disturbance of growth occurred if smooth pins of small gauge were inserted across the epiphyseal plate, but that if pins of large gauge were used some retardation and deformity might ensue. If the smooth pins were removed, the defects in the plate healed with cancellous bone. In treating fractures of the humeral condyles in children, Speed inserted metal nails across the epiphyseal plate for short periods of time and found no evidence of growth disturbance. Charnley likewise found no growth retardation in two children with congenital pseudarthrosis of the tibia in whom intermedullary metallic nails were passed through the central portion of the distal epiphyseal plate of the tibia for fixation.

Our study is concerned with the histological effects and growth disturbance caused by surgical traumata to the epiphyseal plate of immature dogs. Most of the previous experimental work accented the quantitative aspects of growth disturbance, which is certainly more easily analyzed in experimental animals such as rats or rabbits. We were particularly interested in the histology of the epiphys-

TABLE I

OPERATIONS ON IMMATURE DOGS

| Group | Operation | Line Drawing of Operation | No. of Operations | General Effect on Growth |
|---|---|---|---|---|
| 1 | Resection of the margin of the epiphyseal plate, epiphysis, and adjoining metaphysis | | 6 | Minimum angulation |
| 2 | Longitudinal osteotomy through the distal radial and femoral epiphysis crossing the plate in a plane perpendicular to it | | | |
| | a. No internal fixation | | 5 | Minimum retardation |
| | b. Internal fixation—one screw transversely across the metaphysis | | 15 | Minimum retardation |
| | c. Detachment of all soft tissues from fragment, with replacement and fixation | | 5 | Maximum retardation |
| | d. Detachment of soft tissues, insertion in 90 per cent alcohol for ten minutes, replacement, and fixation | | 3 | Maximum retardation |
| 3 | Longitudinal osteotomy in the metaphysis of the radius extending distally to the epiphyseal plate with separation across the plate in the line of cleavage | | 15 | Variable retardation (none to moderate) |
| 4 | Drilling of holes longitudinally across the distal epiphyseal plate of the radius and femur | | | |
| | a. One hole, one-quarter of an inch in diameter | | 2 | Maximum retardation |
| | b. One hole, five-thirty-seconds of an inch in diameter | | 13 | Minimum retardation |
| | c. One hole, five-thirty-seconds of an inch in diameter, with the insertion of beeswax | | 5 | Minimum retardation |
| | d. Eight to ten holes, 0.45 millimeter in diameter | | 5 | No retardation |
| 5 | Longitudinal insertion of cortical-bone graft (homogenous), five-thirty-seconds of an inch in thickness, through a drill hole across the distal epiphyseal plate of the femur | | 8 | Arrest |
| 6 | Longitudinal insertion of smooth metallic pins extending from the articular surface of the epiphysis into the metaphysis of the distal part of the femur and radius | | | |
| | a. Steinmann pin, five-thirty-seconds of an inch | | 14 | Minimum retardation |
| | b. Five Kirschner pins, 0.045 centimeter | | 4 | Variable retardation (none to minimum) |
| 7 | Longitudinal insertion of threaded metallic pins (one-quarter of an inch and five-thirty-seconds of an inch) from the articular surface of the epiphysis into the metaphysis of the distal part of the femur | | 17 | Arrest |

cal plate, and after preliminary work on different experimental animals, we chose the dog, since the growth and behavior of the epiphyseal plate in this animal seemed to more closely resemble that in man.

## PROCEDURE

One hundred and seventeen operative procedures (Table I) were performed under intravenous nembutal anesthesia on sixty-five immature dogs from three to six months of age. Operations were done on the long bones of one side only, so that those of the other side could be used as controls. The animals were sacrificed at two, four, and six weeks, at three months, and, occasionally, at longer intervals after operation. Roentgenograms were made to determine inequality in length, deformity, width of the epiphyseal plate, and the trabecular pattern of both the metaphysis and epiphysis. The bones were cut in half longitudinally and fixed in formalin, and after decalcification in dilute sulfosalicylic acid they were embedded in celloidin, sectioned, and stained with hematoxylin and eosin.

The purpose of the experiments reported here is to study in detail the histological changes and growth disturbance which result from various types of surgical trauma to the epiphyseal plate in immature dogs. In evaluating whether the growth retardation or arrest was minimal, moderate, or maximal, due consideration was given to the age of the dog, the over-all size of the animal (which in mongrel dogs varies considerably), and the time interval between the operation and sacrifice. If the inequality was not more than one or two millimeters, it was classified as minimal, if between three and six millimeters, it was classified as moderate, and if more than six millimeters, as maximum. The expected growth in control animals in which a complete growth arrest was accomplished and in those where normal growth continued, tended to verify this gross classification.

A quantitative analysis of the amount of retardation was not possible because of the variation in growth potential and the difficulty in ascertaining the exact age in mongrel dogs. Even in the general age group under investigation, a complete arrest of growth would often give rise to no more than six to twelve millimeters of arrest in growth of the long bone.

## RESULTS

### *Group 1: Resection of the Margin of the Epiphyseal Plate, Epiphysis, and Adjoining Metaphysis*

The roentgenograms showed a deformed epiphysis with a minimal retardation of growth on its lateral side with some lateral angulation of the bone (Fig. 2-A). Histological examination showed that in all cases there was an osseous bridge across the epiphyseal plate at the site of the ostectomy (Fig. 2-B). A comparison of the lateral margin of the partially excised epiphyseal plate (Fig. 2-B) with the normal (Fig. 1-B) revealed narrowing with irregularity of contour and invagination of the margin into the metaphysis. The cartilage cells near the excised margin of the plate are clumped and irregular in arrangement with marked distortion of the columns.

### *Group 2: Longitudinal Osteotomy through the Distal Radial and Femoral Epiphysis Crossing the Plate in a Plane Perpendicular to It*

Osteotomies through the distal radial and femoral epiphyses which were in a plane perpendicular to the plate and deep enough to extend through a portion of the metaphysis were done in thirty dogs. The fragments consisting of epiphysis, epiphyseal plate, and metaphysis, which were thus formed, were treated in various ways (Table I).

Growth retardation (Fig. 3-A) occurred in most instances, and if the osteotomy was eccentrically placed (Fig. 6) it caused some angulation of the epiphysis. The amount of retardation was greater if the circulation to the detached fragment was severed (Fig. 5-A), and it was maximal if the entire fragment was necrotized

FIG. 1-A

FIG. 2-A

Fig. 1-A: Photomicrograph (× 2.5) of a longitudinal section through a normal epiphyseal plate of the distal part of the femur of a three-month-old dog.

Fig. 2-A: Photomicrograph (× 2) of a longitudinal section through the epiphyseal plate of the distal part of the femur of a four-month-old dog one month after a partial surgical resection of the margin of the epiphysis, the epiphyseal plate, and the adjoining metaphysis. There is a minimum valgus deformity with retardation of growth of the lateral half of the epiphyseal plate.

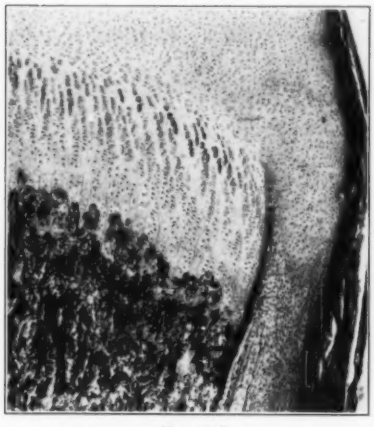

FIG. 1-B

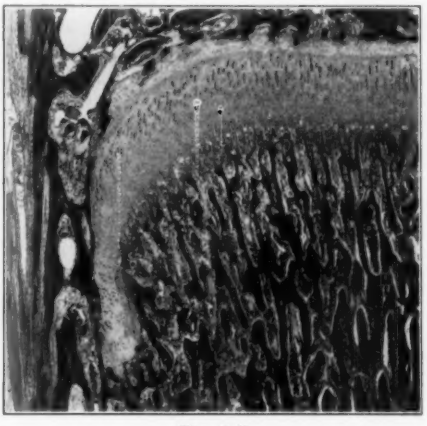

FIG. 2-B

Fig. 1-B: Photomicrograph (× 44) of the margin of the epiphyseal plate shown in Fig. 1-A. The zones of the maturing cartilage are normal. Although a small margin of membranous ossification (*Vencoche de Ranvier*) is located along the outer margin of the plate, it was not a constant finding.

Fig. 2-B: Photomicrograph (× 15) of the lateral margin of the epiphyseal plate shown in Fig. 2-A. A cancellous-bone bridge extends between the epiphysis and metaphysis along the margin of the epiphyseal plate. The margin of the plate extends into the metaphysis. The cartilage cell columns are disoriented so that the zones of the epiphyseal plate cannot be defined.

by soaking it in alcohol (Fig. 6). Histological examination showed the formation of a cancellous-bone bridge between the bone of the epiphysis and that of the metaphysis in all specimens (Figs. 4, 5-A, and 6). The amount of retardation was roughly proportional to the size of the defect in the epiphyseal plate which was filled with cancellous bone.

FIG. 3-A

FIG. 3-B

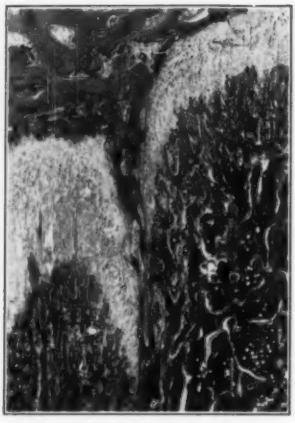

FIG. 3-C

Fig. 3-A: Roentgenogram (× 0.5) six weeks after an osteotomy extending from the epiphysis to the metaphysis close to the margin of the plate. There was minimum growth disturbance.

Fig. 3-B: Photomicrograph (× 1.5) shows an irregularity of the plate with an increased width where the endochondral ossification was impeded by the disruption of the blood supply in the small fragment.

Fig. 3-C: Photomicrograph (× 18) of the point of injury to the plate. With continued growth the margin of the plate invaginates into the metaphysis. A narrow bone bridge crosses the plate.

FIG. 4

FIG. 5-A

Fig. 4: Photomicrograph (× 2) of the longitudinal section of the distal femoral epiphysis eight weeks after a longitudinal osteotomy in a three-month-old dog. A bone bridge connects the epiphysis to the metaphysis. Endochondral ossification of the epiphyseal portion of the fragment is retarded.

Fig. 5-A: Photomicrograph (×2) of a longitudinal section through the distal part of the femoral epiphysis six weeks after an osteotomy extending through the plate. The fragment was detached from the surrounding soft tissue and reattached by use of two metal screws. A cancellous-bone bridge crosses the osteotomy site between the epiphysis and metaphysis. A portion of the plate in the detached fragment has been destroyed and replaced with fibrous tissue and cancellous bone.

FIG. 5-B

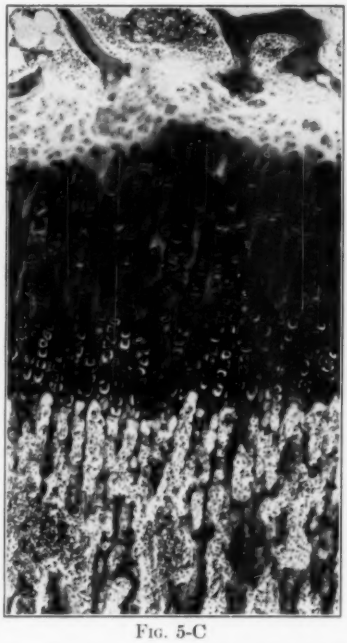

FIG. 5-C

Fig. 5-B: Photomicrograph (× 65) of the margin of the site of ostectomy through the distal part of the femur (Fig. 5-A) shows a thinning and irregularity of pattern involving all the zones of the epiphyseal plate with extension of the margin of the plate into the metaphysis.

Fig. 5-C: Photomicrograph (× 65) of the opposite side of the epiphyseal plate of the distal part of the femur illustrated in Fig. 5-A, showing the cellular detail and pattern of a normal epiphyseal plate. There is a gradual transition from the abnormal findings seen in Fig. 5-B to the normal epiphyseal plate seen in this section.

Fig. 6: Photomicrograph (× 2) of an extreme deformity of the distal part of the femoral epiphysis eight weeks after a longitudinal osteotomy in which the fragment was removed and soaked in 90 per cent alcohol before reinsertion. The necrotic and nonfunctioning remnants of the epiphyseal plate of the detached fragment can be distinguished.

FIG. 6

*Group 3: Longitudinal Osteotomy in the Metaphysis of the Radius Extending Distally to the Epiphyseal Plate with Separation across the Plate in the Line of Cleavage*

There was some growth retardation in all but a few instances, although this was usually minimum (Figs. 7-A and 7-B). Histological examination showed the amount of damage to the immature and undifferentiated cartilage cells located on the epiphyseal side of the columns (Fig. 8-D). A premature closure of that portion of the plate occasionally occurred (Fig. 8-B) with the formation of bone between the epiphysis and metaphysis.

FIG. 7-A

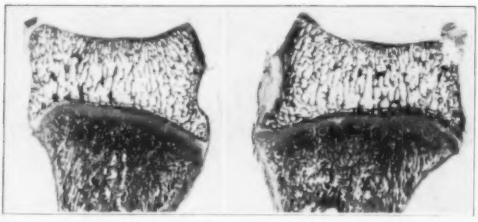

FIG. 7-B

Fig. 7-A: Roentgenogram (× 1.5) showing a minimal growth retardation ten weeks after an osteotomy of the metaphysis with a separation through the epiphyseal plate. A later study of the epiphyseal plate revealed no histological abnormality in this instance.

Fig. 7-B: Photomicrograph (× 1.5) shows no narrowing or intrinsic abnormality in the epiphyseal plate after osteotomy in the line of cleavage.

Fig. 8-A: Roentgenogram (× 0.5) showing minimum growth retardation ten weeks after an oblique osteotomy of the distal metaphysis of the radius which extended to the epiphyseal plate and then passed through the natural line of cleavage of the epiphyseal plate to the opposite side.

Fig. 8-B: A higher magnification (× 1.5) of the roentgenogram (Fig. 8-A) shows marked narrowing of the epiphyseal plate, suggesting premature closure. The epiphyseal plate (× 1.5) on the control side is normal.

Fig. 8-C: Photomicrograph (× 1.5) showing that the epiphyseal plate is closed. There are fragmentation and disorientation of remnants of cartilage.

Fig. 8-D: Photomicrograph (× 70) showing a complete destruction of all zones of the plate. Remaining fragments of epiphyseal cartilage are degenerated and disoriented.

FIG. 8-A

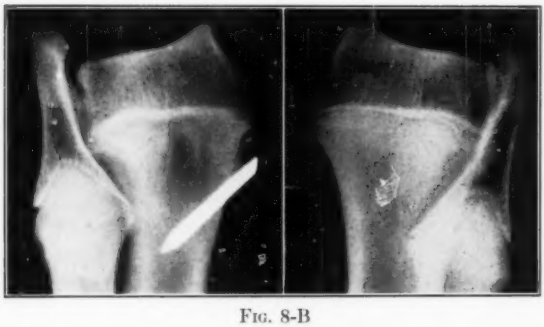

FIG. 8-B

FIG. 8-C

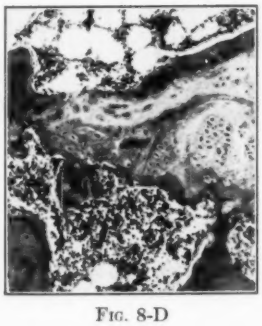

FIG. 8-D

FIG. 9-A

FIG. 9-B

Fig. 9-A: Photomicrograph (× 2) showing the location of a drill hole, five-thirty-seconds of an inch in diameter, through the epiphyseal plate of the distal part of the femur two weeks after the operation. There is a bridge of cancellous bone between the epiphysis and metaphysis.

Fig. 9-B: Photomicrograph (× 45) of the margin of the epiphyseal plate (Fig. 9-A) showing cancellous bone in the defect. There is narrowing of the cartilage plate associated with abnormal cartilage columns. A transversely oriented defect in the cancellous bone suggests a possible infraction of the bone bridge.

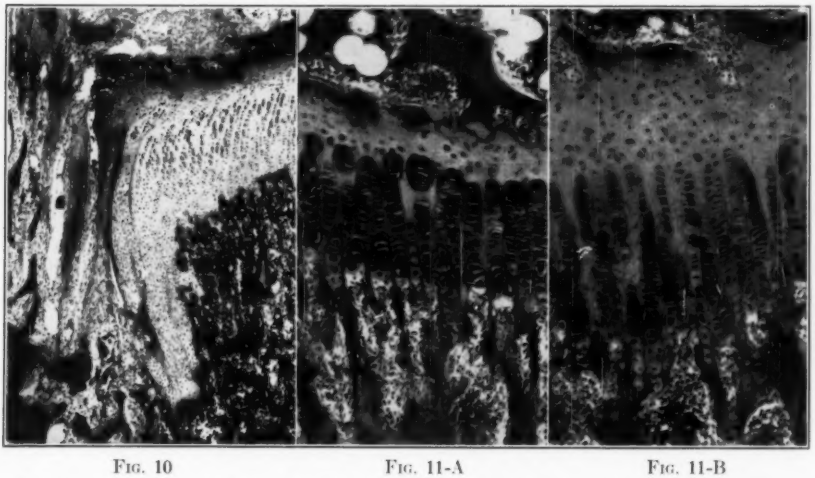

FIG. 10

FIG. 11-A

FIG. 11-B

Fig. 10: Photomicrograph (× 65) of the margin of a drill hole three weeks after operation in a four-month-old puppy shows an invagination of the cartilaginous margin into the metaphysis. Between the cartilage and fibrous tissue of the fibrous portion of the bridge a streak of membranous bone resembling *l'encoche de Ranvier* (Fig. 1-B) has formed. It was not a constant finding.

Fig. 11-A: Photomicrograph (× 98) of a part of the epiphyseal plate adjoining a bone bridge caused by drilling a hole, five-thirty-seconds of an inch, through the plate. Four weeks after operation there is a narrowing of all phases (Streeter) of growth.

Fig. 11-B: Photomicrograph (× 98) of a part of the epiphyseal plate (Fig. 11-A) distant from the point of injury. The epiphyseal plate is normal.

FIG. 12

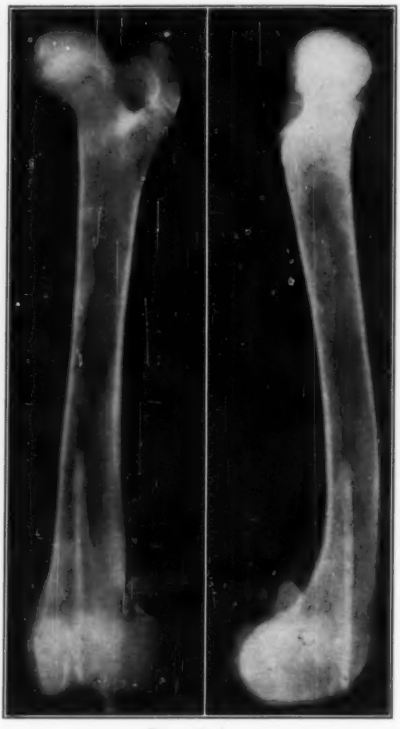

FIG. 13-A

Fig. 12: Roentgenogram showing the radius twenty weeks after the placing of beeswax in a hole, five-thirty-seconds of an inch in diameter, drilled through the distal radial epiphysis of a three-month-old dog. Because of the formation of a sclerotic wall around the margin of the wax, its location can be identified. The bone continued to grow normally so that the wax in the epiphysis became separated from that in the metaphysis. The interval was filled with cancellous bone which was similar in appearance to that found in drill holes (Figs. 9 and 10). There was no evidence of any growth retardation.

Fig. 13-A: Roentgenogram showing a fresh, homogenous cortical-bone graft six weeks after its insertion into a drill hole, five-thirty-seconds of an inch, placed across the epiphyseal plate. Growth was arrested.

*Group 4: Drilling of Holes Longitudinally across the Distal Epiphyseal Plate of the Radius and Femur*

When the one-quarter-inch drill point was used, most of the central portion of the epiphyseal plate was destroyed and rapidly filled with cancellous bone, causing marked growth retardation. When a five-thirty-seconds-inch drill point was used, minimal growth retardation usually resulted. Histological examination of longitudinal sections through the drill holes showed a cancellous-bone bridge between the epiphysis and diaphysis (Figs. 9-B and 10). The margins of the epiphyseal plate bordering this defect invaginated into the diaphysis (Figs. 9-B and 10). The results were similar if holes of five-thirty-seconds of an inch in diameter were filled with beeswax (Fig. 12). If eight to ten holes of small gauge (0.45 millimeter) were made longitudinally and obliquely through the epiphyseal plate, no growth disturbance was noted.

*Group 5: Longitudinal Insertion of a Cortical-Bone Graft (Homogenous), Five-thirty-seconds of an Inch in Thickness, through a Drill Hole across the Distal Epiphyseal Plate of the Femur*

A complete arrest occurred in all instances. If the same operative procedure

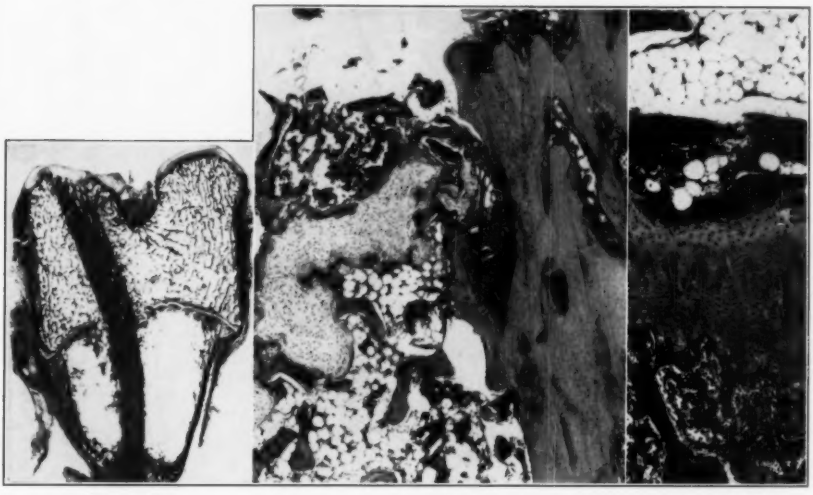

FIG. 13-B FIG. 13-C FIG. 13-D

Fig. 13-B: Photomicrograph (× 2) of a homogenous cortical-bone graft eight weeks after insertion across the distal femoral epiphysis.

Fig. 13-C: Photomicrograph (× 42) of the margin of the graft shown in Fig. 13-B. There is marked irregularity and disorientation of the cartilage columns of the plate.

Fig. 13-D: Photomicrograph (× 42) of the side of the plate farthest from the bone graft (Fig. 13-B) shows narrowing of all zones, fibrillation, and some irregularity of the cartilage columns and contour of the plate. Although the epiphyseal plate is degenerating it is still open.

was done, except for the fact that the graft was broken transversely at the point where it passes through the epiphyseal plate, only minimal retardation of growth occurred.

*Group 6: Longitudinal Insertion of Smooth Metallic Pins from the Articular Surface of the Epiphysis into the Metaphysis of the Distal Femur and Radius*

The roentgenograms showed no evidence of growth retardation in most of the younger animals sacrificed at six weeks, although it was present to a small extent in older animals when they were sacrificed close to maturity (Fig. 15); it was maximum in one animal (Fig. 16). Histological examination showed the width of the epiphyseal plate to be uniform and normal except in the immediate area of the pin, where there was thinning associated with an irregularity in the arrangement of the cartilage cells (Figs. 17 and 18). The margin of the epiphyseal plate adjoining the metallic nail sometimes showed some irregularity in the cartilage columns, and a dense fibrocartilage or fibrous tissue sometimes formed between the metal and cartilage (Fig. 17). Between the nail and the epiphyseal plate cancellous bone sometimes formed a bridge connecting the epiphysis to the metaphysis (Fig. 18). Five Kirschner wires of 0.045 millimeter were placed longitudinally across the epiphyseal cartilage in four puppies, with minimum or no effect on growth (Fig. 20).

*Group 7: Longitudinal Insertion of Threaded Metallic Pins One-quarter of an Inch and Five-thirty-seconds of an Inch from the Articular Surface of the Epiphysis into the Metaphysis of the Distal Femur*

The roentgenograms showed a complete arrest of longitudinal growth at the internally fixed epiphysis (Fig. 21-A). Histological examination five weeks after operation showed a narrowing of the epiphyseal plate with an irregularity of contour (Figs. 21-B and 21-C). Associated with this mechanical arrest there were often protrusions or herniations of cartilage into the epiphysis from the zone of

FIG. 14-A

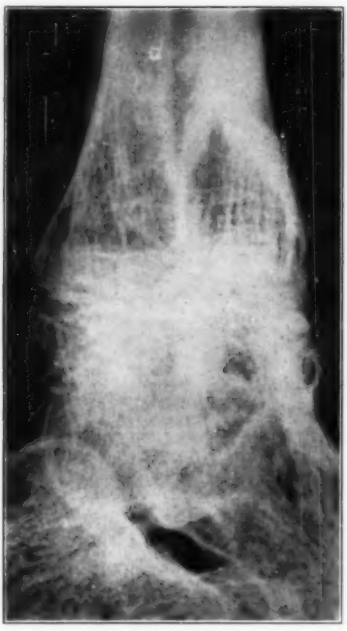

FIG. 14-B

Fig. 14-A: Lateral roentgenogram of the ankle of a ten-year-old boy six months after an arthrodesis of the ankle by use of the Hatt technique in 1948. A cortical-bone graft extends from the metaphysis through the epiphyseal plate and epiphysis of the tibia into the talus.

Fig. 14-B: A lateral roentgenogram one year later (1949) shows absorption of the graft with a fracture of it on the metaphyseal border of the plate.

resting cartilage (Streeter's Phase 1) (Fig. 21-C). The arrangement of the cartilage cells in the plate became irregular, and degenerative changes leading rapidly to closure of the plate ensued. Along the margin of the threaded pin (Fig. 21-C) there was no invagination of the epiphyseal plate into the metaphysis.

### HISTOLOGICAL ANALYSIS OF THE EPIPHYSEAL PLATE AFTER TRAUMA

In those instances where there is growth retardation or arrest because of an injury to one portion of the epiphyseal plate, histological examination revealed the following data:

There was an osseous union between the epiphysis and diaphysis either at the point of injury within the plate or along its margin.

If the arrest was immediate and complete, the epiphyseal plate was narrowed and became increasingly narrow and irregular in contour. The cartilage columns became shortened and irregular, with clumping of the cells. Gradually, all uniformity of the epiphyseal cartilage pattern disappeared (Figs. 13-C and 21-C). The proliferating cartilage of Phase 1 (Streeter) sometimes herniated into the epiphysis (Fig. 21-D). The zone of calcified cartilage increased, and there was a cessation of vascular invasion on the metaphyseal side of the plate, with the formation of a zone of ossification along its border. Calcification and ossification rapidly continued until there was no intervening cartilage between the epiphysis and metaphysis, and the epiphyseal plate was closed.

If there was growth retardation, the epiphyseal plate closest to the point of injury was decreased in width (Figs. 5-B and 11-A), but at a distance from the site of injury, the plate became progressively wider as the distance increased

FIG. 14-C

FIG. 14-D

Fig. 14-C: Lateral roentgenogram two years later (1950) shows a separation of the cortical fragments. The separation is in the metaphysis and represents the amount of growth of the distal tibia after the fracturing of the graft.

Fig. 14-D: Lateral roentgenogram three years later (1951) shows the continuation of growth at the epiphyseal plate three and one-half years after the ankle fusion.

(Figs. 5-C and 11-B). In that portion where the epiphyseal plate was thickest, the contour, pattern of the cartilage columns, and all zones of the plate were essentially normal in appearance. In the narrowed portion of the plate all phases (Streeter) or zones (Ham) were affected. The cartilage columns became stunted and irregular. Clefts and small areas of degeneration formed, and, finally, there was often no recognizable pattern in the arrangement of the cells.

In the epiphyseal plates in which there was retardation but still evidence of growth at the point of injury despite the formation of a cancellous-bone bridge between the metaphysis and epiphysis, there was always an invagination of the cartilage epiphyseal plate into the metaphysis (Figs. 2-B, 3-C, 5-B, 9-B, 10, and 18).

## DISCUSSION

Growth disturbance in these experiments resulted from (1) injury to the epiphyseal plate, with the formation of a cancellous-bone bridge crossing the defect, and (2) effective fixation of the epiphysis to the metaphysis by means of mechanical devices such as a screw, or by firm fusion of a cortical-bone graft to the epiphysis and metaphysis.

There is some variation in the individual response to essentially identical traumata by animals within the same species. This variation may be attributed to small differences in surgical technique, in the circulatory disturbance resulting from the operation, and in the individual animal's response to trauma. Other factors, such as diet, hormonal influences, age, general health, and infection, may also have some influence.

A comparison of the results after resection of the margin of the plate, longitudinal osteotomy, drilling of holes, and the insertion of smooth metallic pins in the epiphyses of dogs of the same over-all build and age indicated that the

FIG. 15

FIG. 16

Fig. 15: Roentgenogram showing an intramedullary stainless-steel pin, one-eighth of an inch, thirty weeks after insertion in the femur of a three-month-old dog. This pin remained in the location of its original insertion. The epiphyseal plate continued to grow so that it was displaced distal to the pin, and the defect was filled with cancellous bone. There was six millimeters of retardation of growth, which is minimal considering the time interval.

Fig. 16: Roentgenogram of an intramedullary pin, five-thirty-seconds of an inch, in the distal part of the femur twenty weeks after insertion in a three-month-old dog. The position of the pin had not changed, and there was an arrest of growth in the distal femoral epiphyseal plate. There was twelve millimeters of inequality of leg length, which was maximum considering the age of the animal and the time interval. This suggests that the intramedullary pin was firm in its fixation of the epiphysis to the metaphysis so that growth ceased.

amount of retardation seems to be roughly proportional to the size of the cancellous-bone bridge connecting the epiphysis to the metaphysis. Angulation deformities may occur if the injury is eccentrically placed. If there is some growth retardation, a lag in the growth of the plate can be seen at the site of the cancellous-bone bridge. This is manifested on either roentgenographic or histological examination by a dipping of the plate into the metaphysis. Ross and Sissons noted similar findings in some epiphyseal plates in children in which growth retardation had occurred after prolonged disability of the lower extremity. It is also found in some cases of growth retardation after fractures, and was observed by Siffert and Ford after experimental trauma to the epiphyseal plate in rabbits. This dipping of the plate occurred when there was a period of growth retardation, but did not occur after an acute arrest. Histological examination of the epiphyseal plates after retardation of growth caused by direct injury to the plate showed narrowing of all phases of cartilage growth adjoining the site of injury. The cartilage columns were disoriented, with the formation of fissures and degenerative changes in the matrix; there was a gradual transition from this condition to the normal appearance of the plate as the distance from the point of injury was increased. There was nothing to suggest that one particular portion of the plate reacted differently to an injury than another. However, the location of the injury

FIG. 17

FIG. 18

Fig. 17: Photomicrograph (× 2.5) of the epiphyseal plate of the distal part of the femur of a three-month-old dog two weeks after the insertion of a stainless-steel pin, five-thirty-seconds of an inch. There is an alteration in the shape of the plate which curves into the metaphysis, reaching its peak at the margin of the pin.

Fig. 18: Photomicrograph (× 35) showing the margin of an epiphyseal plate six weeks after insertion of a smooth nail, five-thirty-seconds of an inch in diameter. In this instance there is a bridge of cancellous bone located between the metallic pin and the remaining portion of the plate which connects the epiphysis to the metaphysis. The plate invaginates into the metaphysis.

in the epiphyseal plate affected the development of angulation deformities.

It is of interest that longitudinal growth may continue in the injured epiphyseal plate despite the bridge of cancellous bone extending between the epiphysis and diaphysis. In all dogs sacrificed three weeks or more after an injury through the epiphyseal plate there was cancellous bone bridging the defect. If this bridge was large, or if cortical bone was placed in the defect, there was growth arrest. If the cancellous bridge was small (in dogs the equivalent of a hole of five-thirty-seconds of an inch or less) there often was continued growth. We did not observe any obvious fractures in these bone bridges. The exact mechanism by which growth occurred was not clarified by the study of these microscopic sections. However, it was obvious that finely trabeculated cancellous bone was affected by the growth force of the plate so that growth in length occurred in some cases.

A smooth metallic pin or intramedullary rod, if it does not cause rigid fixation, may act only as a rod along which the growing end of the epiphysis glides. By filling most of the defect in the plate the rod may leave minimum space in which cancellous bone may form. In our experiments and those of Ford and others [19,60] a rod across the epiphyseal plate produced less growth retardation than a hole of similar size filled with cancellous bone. Conversely, if the pin was removed or displaced, leaving a defect which became filled with cancellous bone, an increase in bone retardation occurred. A soft and pliable substance, such as beeswax, does not act in the same fashion as the rod, since that portion in the metaphysis separates from that portion lying within the epiphysis, and the space left between is filled with cancellous bone.

In this study, if cortical bone was placed across an epiphyseal plate, growth in length was arrested for as long as the graft was intact and fixed to the cancellous bone of both the epiphysis and the metaphysis. Our more recent work, which has not been published, showed that if the graft was broken at the level of the epiphyseal plate, growth resumed if the plate was not completely degenerated or closed. With growth, the graft fragment in the epiphysis separated from that

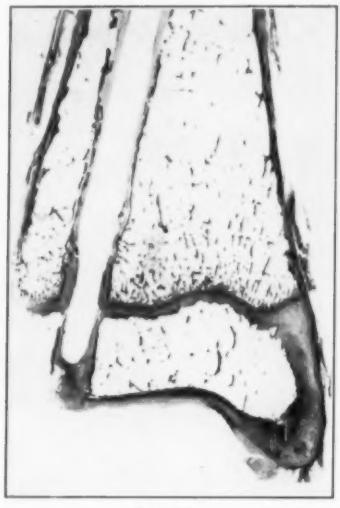

FIG. 19

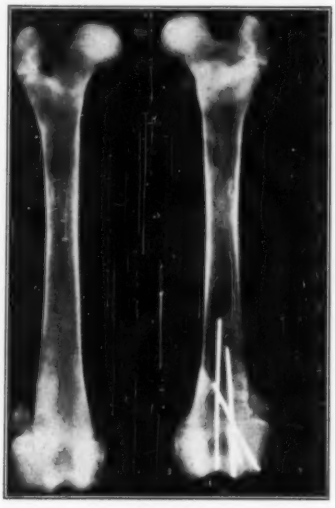

FIG. 20

Fig. 19: Photomicrograph of the distal tibial epiphysis of a nine-year-old child six months after the insertion of a smooth metallic pin across the epiphysis. There is an invagination of cartilage into the metaphysis in this case, similar to that in the puppy, with no evidence of growth disturbance at this time. Note the relatively small size of the pin when considering the size of the plate.

Fig. 20: Roentgenogram (× 0.5) showing multiple Kirschner wires crossing the epiphyseal plate six weeks after their insertion. There was a minimal retardation of growth.

FIG. 21-A

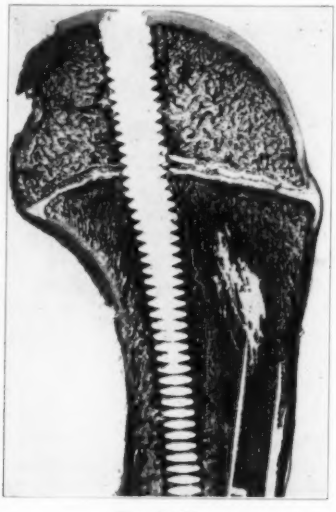

FIG. 21-B

Fig. 21-A: Roentgenogram showing a threaded stainless-steel pin, five-thirty-seconds of an inch, crossing the epiphyseal plate five weeks after its insertion in a five-month-old dog. There is arrest of growth with six millimeters of inequality of leg length.

Fig. 21-B: Photomicrograph (× 2.5) showing a marked narrowing of the epiphyseal plate five weeks after the insertion of a threaded pin. There is an irregularity of contour of the plate and it does not extend into the metaphysis.

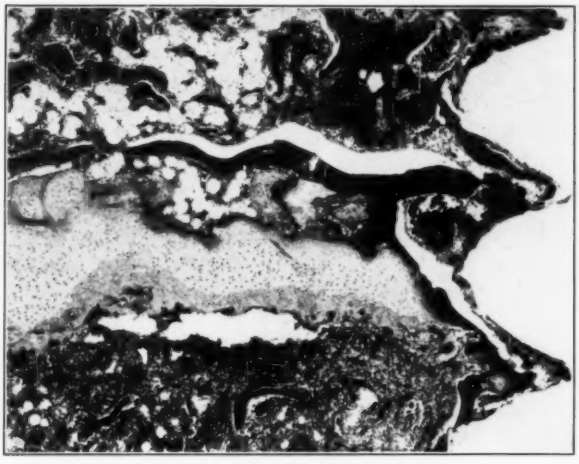

FIG. 21-C

Higher magnification (× 28) of the epiphyseal plate of Fig. 21-B showing the marked distortion of the cartilage columns and the complete disorientation of the cells. Vascular buds have ceased invading the layers of calcified cells. Herniations of immature cartilage into the epiphysis are frequent. The margins of the plate adjoining the threaded pin have ossified.

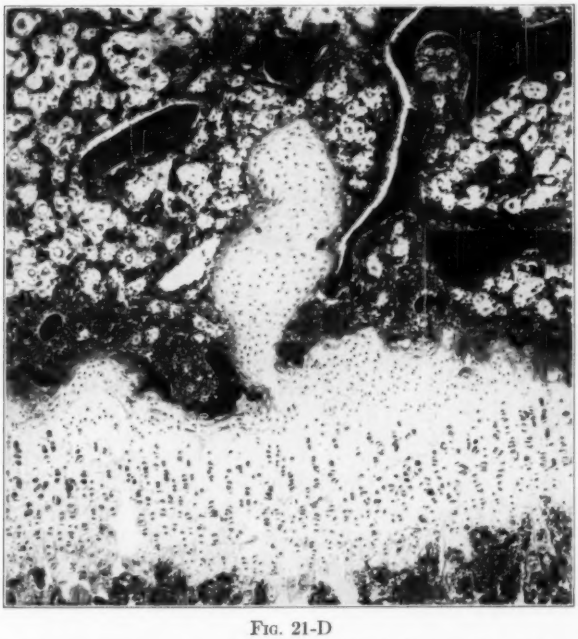

FIG. 21-D

Photomicrograph (× 49) of the epiphysis four weeks after an acute arrest of growth shows a herniation of the immature cartilage of Phase I (Streeter) into the epiphysis.

in the metaphysis, and the interval between these fragments was filled with cancellous bone. Serial roentgenograms of the ankle of a twelve-year-old boy obtained during the first four years after a Hatt arthrodesis showed an arrest of growth for only as long as the cortical-bone graft remained intact (Fig. 14-A). As the result of gradual absorption, the graft fractured (Fig. 14-B) at the level of the epiphyseal plate, and normal growth was resumed. The two graft fragments continued to separate with further growth, and the interval between them was filled with cancellous bone (Figs. 14-C and 14-D). The basic reaction in this child and in an experimental animal was the same. In the immature dog, however, there is only a short period from the time of injury until the plate closes normally, with the result that the cortical grafts do not have time to be absorbed. If, however, the grafts are experimentally fractured or if they break, the response of the plate is similar to that in this child.

Mechanical fixation of the epiphysis to the metaphysis by any means, such as coarsely threaded pins or screws, will arrest growth completely unless the metal fixation is removed before the epiphyseal plate is so disorganized that its growth potential has disappeared. There have been no investigations to determine how long metallic fixation can remain without causing growth retardation or arrest in any species. In this study, most of the threaded pins remained in the bone until the time of sacrifice of the animal. In three puppies the threaded pins were removed only to ascertain that thereafter growth was possible. Histological examination at intervals after the insertion of a coarsely threaded pin showed evidence of marked compression at the level of the epiphyseal plate, with herniations of the undifferentiated cartilage of Phase 1 (Streeter) into the epiphysis. The plate rapidly became narrowed, with degeneration of the cartilage columns, and the changes accompanying the closure of the epiphyseal plate ensued.

## CONCLUSIONS

1. One hundred and seventeen operative procedures were perfomed on the distal femoral and radial epiphyses of sixty-five immature mongrel dogs which were between three and six months of age.

2. After epiphyseal injury in an immature animal of specified age and growth potential, the amount of retardation of growth is roughly proportional to the amount of destruction of the region or zone of the epiphyseal plate which is responsible for replenishing the cells of the cartilage columns.

3. A defect in the cartilaginous epiphyseal plate caused by trauma which extends from the epiphysis to the metaphysis is not repaired by cartilage with the structural pattern of the normal epiphyseal plate. If there is nothing to obstruct the ingrowth of tissue, the defect is filled at first by an undifferentiated mesenchymal tissue which later forms a cancellous-bone bridge.

4. A bone may continue to grow in length normally if a relatively small cancellous-bone bridge connects the epiphysis to the metaphysis. When retardation occurs, the amount of retardation is usually proportional to the size and stability of the bone bridge. A cortical-bone graft, when placed across an epiphyseal plate, causes growth arrest if it unites to the bone of the epiphysis and metaphysis and does not break or is not absorbed.

5. Smooth metallic pins or nails of small gauge inserted from the epiphysis into the metaphysis at an angle perpendicular to the epiphyseal plate may cause less growth retardation than a cancellous-bone bridge of equal size. With growth, the epiphysis may glide over the pin if there is sufficient growth potential left in the epiphyseal plate.

6. Threaded pins or screws placed across the epiphyseal plate cause growth arrest if the threads are of sufficient gauge so that the epiphysis is mechanically fixed to the metaphysis unil the epiphyseal plate is closed.

NOTE: The authors are indebted to Dr. Gary DeN. Hough, Jr., for the case shown in Figure 14, and to Dr. Mary S. Sherman for the case shown in Figure 19.

## REFERENCES


1. Banks, S. W., and Compere, E. L.: Regeneration of Epiphyseal Cartilage. An Experimental Study. Ann. Surg., **114:** 1076-1084, 1941.
2. Belchier, J. B.: An Account of the Bones of Animals Being Changed to a Red Color by Aliment Only. Philosoph. Trans. Roy. Soc. London, 39 (No. 442): 287-288, 1736.
3. Bisgard, J. D., and Bisgard, M. E.: Longitudinal Growth of Long Bones. Arch. Surg., **31:** 568-578, 1935.
4. Bisgard, J. D., and Musselman, M. M.: Scoliosis. Its Experimental Production and Growth Correction. Growth and Fusion of Vertebral Bodies. Surg., Gynec., and Obstet., **70:** 1029-1036, 1940.
5. Boerma, L.: Ueber das Knochenwachstum. Acta Morphol., **4:** 365-377, 1941-42.
6. Brashear, H. R.: Epiphyseal Fractures of the Lower Extremity. Southern Med. J., **51:** 845-851, 1958.
7. Caffey, John: Clinical and Experimental Lead Poisoning: Some Roentgenologic and Anatomic Changes in the Growing Bones. Radiology, **17:** 957-983, 1931.
8. Caffey, John: Changes in Growing Skeleton after Administration of Bismuth. Am. J. Dis. Child., **53:** 56-57, 1937.
9. Charnley, John: Congenital Pseudarthrosis of the Tibia Treated by the Intramedullary Nail. J. Bone and Joint Surg., **38-A:** 283-290, Apr. 1956.
10. Dodds, G. S. and Cameron, H. C.: Studies on Experimental Rickets in Rats. I. Structural Modifications of Epiphyseal Cartilages in Tibia and Other Bones. Am. J. Anat., **55:** 135-165, 1934.
11. Dubreuil, G.: La croissance des os des mammifères. Compt. Rend. Soc. de Biol., **74:** 756-758, 888-890, 935-937, 1913.
12. Eliot, M. M.; Souther, S. P.; and Park, E. A.: Transverse Lines in X-Ray Plates of the Long Bones of Children. Bull. Johns Hopkins Hosp., **41:** 364-388, 1927.
13. Fell, H. B.: The Histogenesis of Cartilage and Bone in the Long Bones of the Embryonic Fowl. J. Morphol. and Physiol., **40:** 417-459, 1925.
14. Ford, L. T., and Canales, G. M.: A Further Study of Experimental Trauma and Attempts to Stimulate Growth of the Lower Femoral Epiphysis in Rabbits. Presented at the Forum on Fundamental Problems in Orthopaedic Surgery at the Meeting of the American College of Surgeons, San Francisco, California, 1956.
15. Ford, L. T., and Key, J. A.: A Study of Experimental Trauma to the Distal Femoral Epiphysis in Rabbits. J. Bone and Joint Surg., **38-A:** 84-92, Jan. 1956.
16. Friedenberg, Z. B.: Reaction of the Epiphysis to Partial Surgical Resection. J. Bone and Joint Surg., **39-A:** 332-340, Apr. 1957.
17. Gatewood, and Mullen, B. P.: Experimental Observations on the Growth of Long Bones. Arch. Surg., **15:** 215-221, 1927.
18. Gottesleben, Anton: Kalkringe in wachsenden Knochen. Röntgenpraxis, **2:** 673-685, 1930.
19. Green, W. T., and Cohen, Jonathan: Personal Communication.
20. Haas, S. L.: The Relation of the Blood Supply to the Longitudinal Growth of Bone. Am. J. Orthop. Surg., **15:** 157-171, 305-316, Mar. and Apr. 1917.
21. Haas, S. L.: The Changes Produced in the Growing Bone after Injury to the Epiphyseal Cartilage Plate. J. Orthop. Surg., **1:** 67-99, 166-179, 226-239, Feb., Mar., Apr. 1919.
22. Haas S. L.: Interstitial Growth in Growing Long Bones. Arch. Surg., **12:** 887-900, 1926.
23. Haas, S. L.: Mechanical Retardation of Bone Growth. J. Bone and Joint Surg., **30-A:** 506-512, Apr. 1948.
24. Haas, S. L.: Restriction of Bone Growth by Pins Through the Epiphyseal Cartilage Plate. J. Bone and Joint Surg., **32-A:** 338-343, Apr. 1950.
25. Hales, S.: Cited by Lacroix[42] and Sissons[68].
26. Hallock, Halford; Francis, K. C.; and Jones, J. B.: Spine Fusion in Young Children. J. Bone and Joint Surg., **39-A:** 481-491, June 1957.
27. Ham, A. W.: Cartilage and Bone. *In* Special Cytology. Ed. 2, pp. 981-1051. Edited by E. V. Cowdry. New York, Paul B. Hoeber, Inc., 1932.
28. Ham, A. W.: Histology. Ed. 3, pp. 276-288. Philadelphia and Montreal, J. B. Lippincott Co., 1957.
29. du Hamel [H.-L.]: Sur une racine qui a la faculté de teindre en rouge les os des animaux vivants. *In* Histoire de l'Académie Royale des Sciences. Avec les Mémoires de Mathématique et de Physique pour la Même Année 1739. Mémoires, p. 1-13. Paris, l'Imprimerie Royale, 1741.
30. du Hamel [H.-L.]: Sur le développement et la crûe des os des animaux. *In* Histoire de l'Académie Royale des Sciences. Avec les Mémoires de Mathématique et de Physique pour la Même Année 1742. Mémoires, pp. 481-504. Amsterdam, Pierre Mortier, 1747.
31. du Hamel [H.-L.]: Cinquième mémoire sur les os dans lequel on se propose d'éclaircir par de nouvelles expériences comment se fait la crûe des os suivent leur longueur, et de prouver que cet accroissement s'opère par un méchanisme très approchant de celui qu'observe la Nature pour l'alongement du corps ligneux dans les bourgeons des arbres. *In* Histoire de l'Académie Royale des Sciences. Avec les Mémoires de Mathématique et de Physique pour la Même Année 1743. Mémoires, pp. 111-146. Paris, l'Imprimerie Royale, 1746.
32. Hatt, R. N.: The Central Bone Graft in Joint Arthrodesis. J. Bone and Joint Surg., **22:** 393-402, Apr. 1940.
33. Hellstadius, Arvid: An Investigation, by Experiments on Animals, of the Role Played by the Epiphysial Cartilage in Longitudinal Growth. Acta Chir. Scandinavica, **95:** 156-166, 1947.
34. Hinkel, C. L.: The Effect of Roentgen Rays upon the Growing Long Bones of Albino Rats. Am. J. Roentgenol., **49:** 321-328, 1943.

35. Humphry, G. M.: Observations on the Growth of the Long Bones, and of the Stumps. Medico-Chir. Trans., **44:** 117-134, 1861.
36. Hunter, John: The Works of John Hunter, F.R.S. Vol. 1, pp. 253-254; Vol. 4, pp. 315-318. Edited by James F. Palmer. London, Longman, Rees, Orme, Brown, Green, and Longman, 1835.
37. Imbert, R.: Pathologie expérimentale de l'appareil de croissance des os longs. Marseille Chir., **3:** 581-599, 1951.
38. Jahn, Paul: Beiträge zur Kenntniss de histologischen Vorgänge bei der Wachsthumsbehinderung der Röhrenknochen durch Verletzungen des Intermediärknorpels. Morphol. Arb., **1:** 241-266, 1892.
39. Kassowitz, M.: Die Behandlung der Rachitis mit Phosphor. Zeitschr. f. Klin. Med., **7:** 93-139, 1883.
40. von Kölliker, [R.] A.: Die normale Resorption des Knochengewebes und ihre Bedeutung für die Enstehung der typischen Knochenforme. Leipzig, F.C.W. Vogel, 1873.
41. Kornew, P. G.: Transplantation und Knochenwachstum. Arch. f. Klin. Chir., **154:** 499-564, 1929.
42. Lacroix, P.: The Organization of Bones. (Translated from the amended French edition by S. Gilder.) Philadelphia, The Blakiston Co., 1951.
43. Latarjet, A.: Résultats expérimentaux sur l'accroissement des os en longueur. Compt. Rend. Assn. des Anatomistes, Session 14, pp. 72-91, 1912.
44. Leser, E.: Ueber Histologische Vorgänge an der Ossificationsgrenze mit besonderer Berücksichtigung des Verhaltens der Knorpelzellen. Arch. f. Mikrosk. Anat., **32:** 214-222, 1888.
45. Luck, J. V.: The Histogenesis of the Fusion Process and the Use of Transverso-Facet Bone Blocks in Scoliosis. Surg. Forum 1956. **7:** 586-589, 1957.
46. Maksimov, A. A., and Bloom, W.: A Textbook of Histology. Ed. 7, pp. 138-140. Philadelphia and London, W. B. Saunders Co., 1957.
47. McLean, F. C. and Bloom, W.: Calcification and Ossification. Calcification in the Normal Growing Bone. Anat. Rec., **78:** 333-359, 1940.
48. Müller, Heinrich: Ueber die Entwicklung des Knochensubstanz nebst Bemerkungen ueber den Bau rachitischer Knochen. Zeitschr. f. Wissensch. Zool., **9:** 147-233, 1858.
49. Odelberg-Johnson, G.: On Defects and Pseudarthroses of the Bony Bridge Following Paraspinal Bone Transplantation in Growing Rabbits. Acta Orthop. Scandinavica, **10:** 160-219, 1939.
50. Ollier, L.: Traité Expérimental et Clinique de la Régénération des Os et de la Production Artificielle du Tissu Osseux. Vol. 1, pp. 236-238, 386-392. Paris, Masson et Fils, 1867.
51. Payton, C. G.: The Growth of the Epiphyses of the Long Bones in Madder-Fed Pigs. J. Anat. **67:** 371-381, 1933.
52. Phemister, D. B.: The Effect of Phosphorus on Growing, Normal and Diseased Bones. J. Am. Med. Assn., **70:** 1737-1743. 1918.
53. Phemister, D. B.: Operative Arrestment of Longitudinal Growth of Bones in the Treatment of Deformities. J. Bone and Joint Surg., **15:** 1-15, Jan. 1933.
54. Retterer, E.: Évolution du cartilage transitoire. J. de l'Anat. et de Physiol., **36:** 467-565, 1900.
55. Retzius, G.: Zur Kenntniss der enchondralen Verknöcherung. Biol. Fören. Förhandl. Verhandl. d. Biol. Ver. in Stockholm, **1:** 5-8, 1888-89.
56. Risser, J. W.: Scoliosis. *In* Instructional Course Lectures, American Academy of Orthopaedic Surgeons, 1953. Vol. 10, pp. 131-138. Ann Arbor, J. W. Edwards, 1953.
57. Ross, Donald: Disturbance of Longitudinal Growth Associated with Prolonged Disability of the Lower Extremity. J. Bone and Joint Surg., **30-A:** 103-115, Jan. 1948.
58. Selye, Hans: On the Mechanism Controlling the Growth in Length of the Long Bones. J. Anat., **68:** 289-292, 1934.
59. Siegling, J. A.: Growth of the Epiphyses. J. Bone and Joint Surg., **23:** 23-36, Jan. 1941.
60. Siffert, R. S.: The Effect of Staples and Longitudinal Wires on Epiphyseal Growth. J. Bone and Joint Surg., **38-A:** 1077-1088, Oct. 1956.
61. Silfverskiöld, Nils: Über Längenwachstum der Knochen und Transplantation von Epiphysenscheiben. Acta Chir. Scandinavica, **75:** 77-104, 1934.
62. Sissons, H. A.: Osteoporosis and Epiphysial Arrest in Joint Tuberculosis. J. Bone and Joint Surg., **34-B:** 275-290, May 1952.
63. Sissons, H. A.: The Growth of Bone. *In* The Biochemistry and Physiology of Bone, pp. 443-474. Edited by G. H. Bourne. New York, Academic Press, Inc., 1956.
64. Speed, J. S., and Macey, J. B.: Fractures of the Humeral Condyles in Children. J. Bone and Joint Surg., **15:** 903-919, Oct. 1933.
65. Streeter, G. L.: Developmental Horizons in Human Embryos. A Review of the Histogenesis of Cartilage and Bone. Contrib. Embryol., **33:** 149-167, 1949.
66. Villafañe, I. Z.: El crecimiento de los huesos largos. Semana Méd., **45** (2): 44-48, 1938.
67. Vogt, Paul: Die traumatische Epiphysenntrennung und deren Einfluss auf des Längenwachsthum der Röhrenknochen. Arch. f. Klin. Chir., **22:** 343-373, 1878.
68. Wegner, Georg: Ueber das normale und pathologische Wachsthum der Röhrenknochen. Virchow's Arch. f. Pathol. Anat., **61:** 44-76, 1874.

## DISCUSSION

Dr. Fred C. Reynolds, St. Louis, Missouri: Damage to the germinal cells of the epiphyseal cartilage plate from direct trauma, loss of circulation or compression arrests longitudinal bone growth. The damaged epiphyseal plate does not heal with cartilage but with cancellous bone that joins the epiphysis to the metaphysis. Whether the arrest is complete or partial depends on the location and extent of the damage.

It has been demonstrated that a fair amount of damage may be inflicted to the central portion of the epiphyseal plate without causing much growth disturbance even though this area of damage heals with bone that connects the epiphysis and metaphysis. However, even in the centrum, if a large defect is created, or the epiphysis is fixed to the metaphysis with an unyielding substance, considerable retardation or complete cessation of growth results.

It would seem that with the vast amount of work that has been done on the longitudinal growth of bone, and of damage to the epiphyseal cartilage plate, all of the questions concerning bone growth would be readily answered. However, the authors' observations bring up some still unanswered problems. In each instance of damage, in which there is a communication between the epiphysis across the epiphyseal cartilage plate and the metaphysis, healing results in a bone bridge which unites the epiphysis to the metaphysis. If the area of damage is small, growth is but little affected, and in the area of damage there is apt to be dimpling or invagination on the metaphyseal side. The authors feel that this continuation of growth is possible only because of multiple fractures in this cancellous-bone bridge that allow it to increase in length. But if the area of damage is large, so that there is a large bone bridge, then there is marked restriction of growth. This was true in situations in which a homogenous-bone graft was placed across the epiphysis.

On the other hand, Hatt devised a method of arthrodesis of the knee and ankle in which he used an autogenous-bone graft across the epiphysis, and claimed that there was little if any disturbance of growth. In the cases reported, this was used primarily at the knee joint, and many times a large autogenous cortical-bone graft would extend across the epiphysis of the distal part of the femur and the upper part of the tibia. Follow-up examination of these patients from two to six years after operation did not reveal marked retardation of growth.

In the cases illustrated, the graft seemed to be rapidly replaced with living bone and lost its identity. There was a little dimpling on the metaphyseal side of both epiphyseal lines. Is it possible to reconcile these two observations? It seems to me that it may be, because the authors found that when they did an osteotomy and killed the bone by boiling or with chemicals there was much greater retardation of growth than when simple osteotomy and reposition were carried out. In this instance there was damage to the circulation as well as to a larger amount of the epiphyseal cartilage. In addition, there was a slow replacement of the bone, so that a strong bone bridge was maintained for a long time. One also might reason that homogenous bone would be replaced somewhat more slowly than autogenous bone, and that if there was a large homogenous-bone graft placed across the center of the epiphyseal cartilage plate, it might form a firm fixation until the entire graft was replaced with living bone, thus resulting in considerable retardation of growth, whereas autogenous-bone grafts of the same size would be replaced much more rapidly, and, therefore, would result in a smaller amount of disturbance of growth.

Of course, in the instances cited here, there is a tremendous difference in the total area of the epiphyseal cartilage plate involved. It may be that it is actually the amount of the epiphyseal cartilage plate that is damaged, with lessening of the forces, that results in a difference in the behavior. Certainly, in the authors' case cited, in which the Hatt method of arthrodesis had been used for the ankle, it does appear in the illustrations that growth was retarded until the graft separated. This apparently did not occur in any of the cases that Hatt reported. I have never used this method for fusion; perhaps there are persons in the audience who have had experience with it and might comment on this aspect.

The question, then, is raised as to whether or not bone bridging the epiphysis to the metaphysis, either from the healing of trauma or from a graft, increases in length in those instances in which complete arrest does not result. If so, it is by interstitial growth, by multiple fractures, or by appositional new-bone formation. Since there is no evidence either microscopically or by roentgenogram of fractures, and since there is no evidence of interstitial bone growth, it seems more likely that this is a function of appositional new-bone formation in response to the tremendous pressures exerted by the epiphyseal cartilage plate.

Hellstadius resected the distal epiphysis of the ulna in dogs, and found that there was a considerable increase in the length of the ulna. Growth continued in the radius, resulting in bowing of each bone. Bisgard and Musselman fused the spines of goats across undamaged epiphyseal cartilage plates, and claimed that the fusion mass elongated to accommodate for growth in the spine. Haas carried out fusions in dogs, placing markers at either end of the graft, and found that there was no increase in the length of the graft. He also noted that there was some increase in the fusion mass and that if the graft became solid, the disc spaces were compressed. He concluded from these experiments that there was no evidence of interstitial bone growth in the graft. Hallock, Francis, and Jones studied spine fusions in children, and noted that when the spine fusion was solid, there was encroachment upon the disc spaces as the vertebral bodies grew, but that if there was a crack in the graft or this fusion area it was immediately evident from the size of the disc space. They found that there was a retardation of growth of the length of the fused segment of 23 per cent in the bodies, and 43 per cent in the posterior elements, and that there appeared to be growth in the length of the fusion mass.

The exact pressure exerted by the growing epiphyseal cartilage plate has not been measured, but Hirsch found that a 100-kilogram force compressed a disc space one millimeter, so there-

fore the growth force that allows a vertebral body to encroach upon and almost compress the disc space must be quite large.

I would like to suggest that consideration be given to the possibility that forces exerted by the relatively undamaged epiphyseal plate stimulate appositional new-bone formation, with resultant increase in the length of the fusion mass in spine fusion. The experiments of Hellstadius and the increased length of the bone bridge of the damaged epiphysis may be explained in this way. If a large area of the epiphysis is damaged and the growth potential correspondingly reduced, the bone bridge is able to prevent further growth.

Whether or not appositional new-bone formation accounts for the phenomenon just discussed may be readily found by marking with either phosphorus or alizarin.

DR. WALTER P. BLOUNT, MILWAUKEE, WISCONSIN: With their beautifully presented experiments Dr. Campbell and his associates have made several points of importance about the response of epiphyseal plates to injury in puppies. Some of these are applicable to similar situations in children.

They have shown microscopically that traumatic defects of the epiphyseal cartilage heal with bone, not cartilage. A bone bridge across the cartilage plate will stop growth locally, but a small bridge will let go, like a piece of taffy, and permit subsequent growth equivalent to that on the normal opposite side.

If a smooth pin of very small caliber penetrates an epiphyseal cartilage perpendicularly, growth is not retarded, and, after it has been removed, growth will continue normally. The bone bridge that forms in the track is too small to be significant.

Complete growth arrest was produced in puppies by a large screw across the epiphyseal plate. Measurements were made with reference to the screw. If the length of one entire bone is compared with its fellow, as the authors compare bones, it is permissible to refer to moderate or extreme shortening. But if retardation of growth at a certain epiphysis is to be expressed in millimeters as compared with that of another epiphysis, as Dr. Campbell and his associates do also, then a point of reference must be established in the diaphysis. Natural growth lines are sometimes helpful in children, but they are transient and not dependable. Lines have been produced in laboratory animals. Inserting metal markers in the shafts of the bones of both extremities is the only way one can know exactly how much retardation is obtained at each epiphysis. Some such technique should have been used, because the traumata described in the experiments of Campbell and his associates very likely produced accelerated growth at the opposite end of the traumatized bones. They do not consider this possibility, which happens routinely in children. If only the total length is studied, there may be an error because retardation of growth of the traumatized epiphysis may be partially equalized by the accelerated growth of the epiphysis at the opposite end of the bone. To illustrate what I mean, I made a bar graph of the growth increment in teleoroentgenograms of the tibiae of a five-year-old child whose left distal tibial epiphysis was grossly damaged. There was little growth. The right distal epiphysis grew eight millimeters during the first year and eight millimeters the second year. But after epiphyseodesis of the right proximal epiphysis, the distal end grew ten millimeters during the third year. This 25 per cent increase is despite an extremity growth lag, as evidenced by the reduced growth at the left proximal tibial epiphysis which grew only ten millimeters during the same year whereas it had grown twelve millimeters during each of the preceding years. This acceleration of growth at the right distal epiphysis was likely due to the operative trauma at the other end of the bone. For such accurate evaluation, markers must be used.

# The Role of Soft Tissues in Osteogenesis

## An Experimental Study of Canine Spine Fusions *†

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The following studies were originally designed to evaluate the role played by overlying soft tissues during osseous fusion in the spine. Berg hypothesized in 1947 that osteosynthesis in the spine was more surely and rapidly achieved if the paraspinal muscles were elevated from decorticated laminae by bone grafts so that a space was created in which bone-forming granulation tissue could grow. Shortly thereafter, Hellstadius put Berg's theory to test by using stainless-steel cups and rings to elevate muscles from the roughened cortex of a rabbit's femur. He concluded that bone would not form in granulation tissue if the soft parts were held away. The experiments to be reported have utilized several methods, in addition to bone-grafting, to physically separate soft tissues from areas of active bone formation in the spine. One of the methods chosen was to test the hypothesis that proliferating osseous tissue elaborated a diffusible substance that could influence or induce bone formation in overlying soft tissues [14]. No such substance has been demonstrated by these studies.

### MATERIALS AND METHODS ‡

Adult mongrel dogs of both sexes were anesthetized with intravenous pentobarbital sodium, thirty milligrams per kilogram of body weight. After intubation, the animals were attached to an automatic closed-system respirator and ventilated with 100 per cent oxygen. Approximately 300 cubic centimeters of 5 per cent dextrose in distilled water was administered by venoclysis during the operative procedures. One million units of benzathene G penicillin and 1 gram of streptomycin were administered routinely after operation.

A total of sixty-nine interlaminar spaces were prepared for fusion. In thirty-two dogs (the dog normally has seven lumbar vertebrae) arthrodesis was attempted at both the fifth lumbar-sixth lumbar and the seventh lumbar-first sacral levels while in five animals arthrodesis was attempted only at the fifth lumbar-sixth lumbar level. One of four experimental procedures was used at each spinal level (Table I) so that most animals bore two different test situations at the same time (Figs. 1-A and 1-B).

A. *Controls:* A modified Hibbs spine fusion [10,11,12] served as a control (Fig. 1-A). As much intra-articular cartilage as possible was removed from the spinal facets. Fresh autogenous-bone grafts, consisting of cortical-cancellous chips, averaging 0.5 by 0.3 by 1.0 centimeter, were obtained from the iliac crest. These grafts, used to augment decorticated bone chips from the laminae and spinous processes, spanned the interlaminar space in random orientation. This technique was employed at both the fifth lumbar-sixth lumbar and the seventh lumbar-first sacral joints, and served as the basic operative procedure in each of the experimental groups.

B. *Millipore:* Nylon reinforced sheets of HA millipore**, a permeable, plas-

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‡ Fifth lumbar-sixth lumbar and seventh lumbar-first sacral fusions, in which ethylenediamine extracted bone had been added to the fusion site, have been omitted from this report.

** Supplied by Mr. John Bush, Millipore Filter Corporation, Bedford, Massachusetts.

TABLE I

EXPERIMENTAL STUDY OF CANINE SPINE FUSIONS—GROSS OBSERVATIONS

| Experimental Group | Animal Number | Days at Sacrifice | Fusion Solid (S) |
|---|---|---|---|
| I. *Control* | | | |
| A. L5/L6 Joint | 4556 | 30 | S |
| | 305 | 30 | |
| | 258 | 30 | |
| | 331 | 30 | |
| | 4559 | 60 | S |
| | 4510 | 60 | S |
| | 4511 | 60 | S |
| | 4547 | 90 | S |
| | 3954 | 120 | S |
| | 4541 | 120 | S |
| B. L7/S1 Joint | 4514 | 60 | |
| | 4510 | 60 | |
| | 4533 | 90 | |
| | 4491 | 120 | |
| II. *Millipore* | | | |
| A. L5/L6 Joint | 883-B | 30 | S |
| | 887-B | 30 | S |
| | 888-B | 30 | S |
| | 886-B | 30 | S |
| | 889-B | 30 | S |
| | 857-B | 60 | S |
| | 4543 | 90 | S |
| | 4508 | 90 | S |
| | 4509 | 90 | S |
| | 870-B | 120 | S |
| | 884-B | 120 | S |
| | 4537 | 120 | S |
| (II. cont.) | | | |
| B. L7/S1 Joint | 858-B | 15 | S |
| | 844-B | 28 | |
| | 331 | 30 | |
| | 867-B | 40 | |
| | 868-B | 60 | |
| | 4494 | 90 | |
| | 4499 | 90 | |
| | 869-B | 120 | |
| | 881-B | 120 | |
| | 880-B | 120 | |
| III. *Sheet silastic* | | | |
| A. L5/L6 Joint | 844-B | 28 | |
| | 858-B | 15 | |
| | 867-B | 40 | |
| | 856-B | 60 | |
| | 868-B | 60 | |
| | 4494 | 90 | |
| | 4499 | 90 | |
| | 869-B | 120 | |
| | 881-B | 120 | |
| | 880-B | 120 | |
| B. L7/S1 Joint | 883-B | 30 | |
| | 887-B | 30 | |
| | 888-B | 30 | |
| | 886-B | 30 | |
| | 889-B | 30 | |
| | 857-B | 60 | |
| | 4543 | 90 | |
| | 4508 | 90 | |
| | 4509 | 90 | |
| | 870-B | 120 | |
| | 884-B | 120 | |

FIG. 1-A

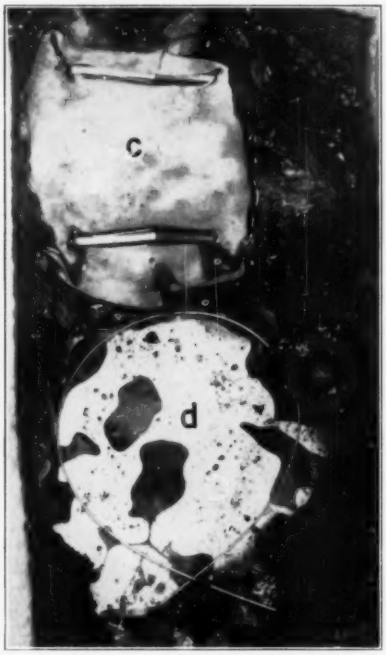


FIG. 1-B

Figs. 1-A and 1-B: Operative sites demonstrating the four experimental techniques.

Fig. 1-A: At *a* ethylenediamine extracted chips cover the autogenous chips at the fifth lumbar-sixth lumbar interspace. (The results are omitted from this report.) At *b* is the control fusion at the lumbosacral joint in which autogenous chips were used.

Fig. 1-B: At *c* millipore covers fusion (similar to that in Fig. 1-A, *b*) at the fifth lumbar-sixth lumbar level. At *d* silastic covers fusion (similar to that in Fig. 1-A, *b*) at the lumbosacral joint.

tic, membrane filter, were interposed between the fusion site and overlying muscle mass (Fig. 1-B, *c*). The 150-micra plastic sheets were cut of sufficient length to extend over the upper and lower limits of the fusion bed and of sufficient width to extend laterally to the transverse processes on either side. In the fifth lumbar-sixth lumbar area the millipore sheets were held in place by two stainless-steel spring clips inserted firmly around the vertebral body (Figs. 1-B, *c* and 2). In the lumbosacral region a loop of stainless-steel spring wire was used instead of the clips (Fig. 1-B, *d*). The position of this wire loop was secured by fixing it into the notches previously cut with an osteotome into the lamina at the base of the spine of the seventh lumbar vertebra above and into the sacrum below.

C. *Silastic*:* Sheet silastic, a silicone rubber, was used as a relatively impermeable, interposition membrane. The material, measuring 0.007 inch thick, was held in place with the same techniques described for millipore (Fig. 1-B, *d*).

Postoperatively, the animals were maintained in small, individual animal cages. No external immobilization was used. Roentgenograms of the spine were made every four weeks and immediately before death in selected cases. The animals were sacrificed thirty, sixty, ninety, and 120 days after operation and the mechanical integrity of the fusion manually tested. Resected, block specimens of the posterior elements of the spine from the fifth lumbar vertebra to the sacrum were separated from the vertebral bodies and then subjected to bending stress. The slightest degree of motion at the facet area was interpreted as evidence of pseudarthrosis.

* Supplied by Dr. R. R. McGregor, Dow Corning Corporation, Midland, Michigan.

Sections were prepared for histological study from specimens fixed in 10 per cent neutral formalin as well as in cold acetone for the demonstration of alkaline phosphatase [6]. Formalin-fixed tissues were decalcified with Schmorl's solution [13], while the acetone-fixed material was decalcified in aqueous versene solution (27.5 grams ethylenediamine tetra-acetic acid, di-sodium salt in 500 cubic centimeters of water). Paraffin and celloidin embedded sections were stained with hematoxylin and eosin, Mallory's trichrome, van Gieson, Masson's trichrome, periodic-acid Schiff (McManus), Gomori's alkaline phosphatase, toluidine blue, and azure A stains. Selected cross sections were studied by microradiography and by polarized light.

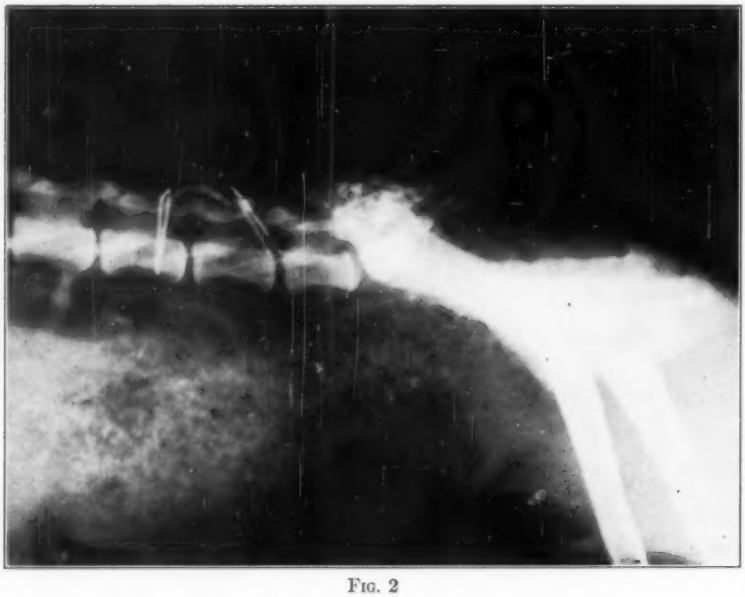

FIG. 2

Roentgenogram shows stainless-steel clips which fixed millipore membranes in position. Prongs are lateral to vertebral bodies.

## RESULTS

### *Gross Observations*

The results of subjecting resected fresh specimens to stress across the intervertebral joints are summarized in Table I. All attempts at lumbosacral fusion (twenty-five animals), regardless of the operative technique employed, resulted in pseudarthrosis. Seven of ten control fusions at the fifth lumbar-sixth lumbar level were solid and presented evidence of thick, continuous, osseous plates at sixty to 120 days. The three animals in the control group in which motion was found were sacrificed at thirty days after operation. The surface of the fusion plate in most control specimens was pitted and irregular. Invaginations of fibrous tissue often projected into clefts in the fusion mass.

All twelve fifth lumbar-sixth lumbar operative areas covered with millipore presented evidence of a solid fusion. The stainless-steel wire clips were in place. Overlying muscle and fibrous fascial tissue, in which no evidence of bone was found, could be easily separated from the filter material. However, millipore was adherent to the underlying osseous bed in some areas. Contours of the bone surface immediately beneath the millipore sheet reflected, as a relief, every fold and wrinkle of the plastic cover. In no instance was a discernible amount of fibrous tissue found deep to millipore.

All ten fusions at the fifth lumbar-sixth lumbar level covered with silastic resulted in pseudarthroses. Three of the dogs died prior to the time of intended sacrifice at fifteen, twenty-eight, and forty days. Autopsy revealed evidence of meningitis in each of these. In the other animals, bone formation was limited to areas immediately adjacent to laminae. Large amounts of fibrous tissue were found deep to the silastic sheets.

*Histological Observations*

A. *Pseudarthrosis:* Sections through the lumbosacral region, regardless of the operative technique used, were characterized by a lack of reactive new-bone formation. On cross section, the very thin laminae merged with a thick area of

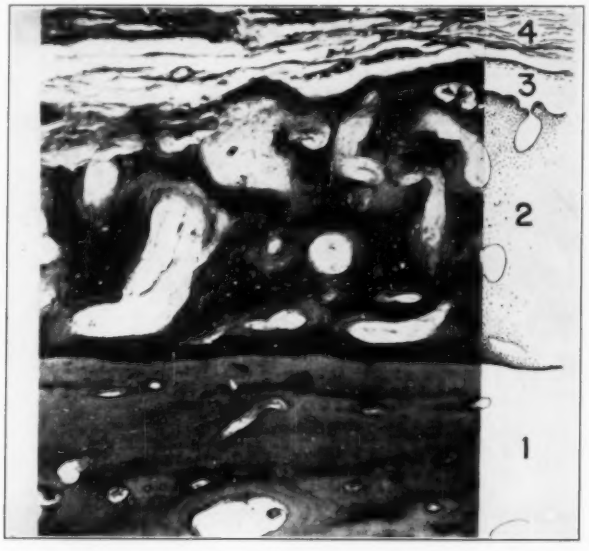


FIG. 3

Cross section through control spine fusion at the fifth lumbar-sixth lumbar interspace at thirty days, illustrating four histological zones (periodic-acid Schiff, × 130). Zone 1, basal layer consisting of laminar bone. Zone 2, reactive, proliferating fiber bone. Zone 3, intermediate granulation tissue. Zone 4, area of well differentiated fibrous tissue and muscle.

poorly vascularized, fibrous connective tissue. Numerous autogenous-bone fragments were found embedded in this dense tissue. These chips appeared to be dead, as judged by the absence of osteocytes in lacunae, and had evoked no osteogenesis in their vicinity. There was no bone bridging across the lumbosacral facets.

The earnest attempts to remove cartilage from the facets were never completely successful. However, despite the relatively large amount of residual articular cartilage, a continuous bridge of callus was found spanning both facets in approximately one-third of the fifth lumbar-sixth lumbar specimens.

B. *Controls:* Cross sections through the fifth lumbar-sixth lumbar control spine fusion sites revealed four specific zones (Fig. 3). The first zone, or the basal layer, consisted of relatively normal, cancellous laminar bone. Many of the surface cells of this layer in the thirty and sixty-day specimens were judged to be dead on the basis of empty lacunae and lighter staining of the bone matrix. Immediately superficial to this layer was a clearly demarcated second zone of reactive, proliferating fiber bone, which appeared as deep purple in the periodic-

acid Schiff stained sections. A third or intermediate zone of loose granulation tissue could be identified between the region of reactive new bone and overlying soft tissues. This narrow region blended rapidly into a more superficial area of moderately dense fibrous connective tissue (fourth zone), in which collagen bundles were arranged roughly parallel to the surface of the osseous fusion mass. Paraspinal muscle fibers were observed in the more superficial portions of the fourth zone.

Bone chips, incorporated in reactive new bone, appeared dead. Most of these had been invaded by vessels and demonstrated various stages of remodeling as early as thirty days. The layer of reactive fiber bone (zone 2) appeared thicker and more mature in the 120-day section, presenting a picture of adult, organized trabecular bone. Most of the chip grafts had been completely remodeled in these older sections.

FIG. 4

Cross section of a control fusion mass at sixty days. Arrow points to large mass of fibrous tissue (Mallory trichrome, × 24).

The line of demarcation at the interface between zones 2 and 3 was irregular. In certain regions, long trabecular projections of bone extended into the more superficial region of fibrous tissue (zone 4). In other regions, thick masses of fibrous tissue were found within the region of active bone formation (zone 2) (Fig. 4). When polarized light was used, continuous collagen bundles were found extending perpendicularly between the zones of fiber bone and granulation tissue. Active osteoblasts at the interface between these zones appeared to be oriented in relation to interconnecting collagen fibers (Fig. 5).

The three control fusions that were classed as failures demonstrated motion on manual stress thirty days after operation. Vigorous new-bone formation and large amounts of immature osteochondroid matrix were found in these specimens. In many regions, however, histologically intact muscle fibers lay intimately upon the basal laminar layer, and in these regions new-bone formation was scanty. Although no mature trabeculae of bone bridged the facets, there was active osteogenesis taking place in the area.

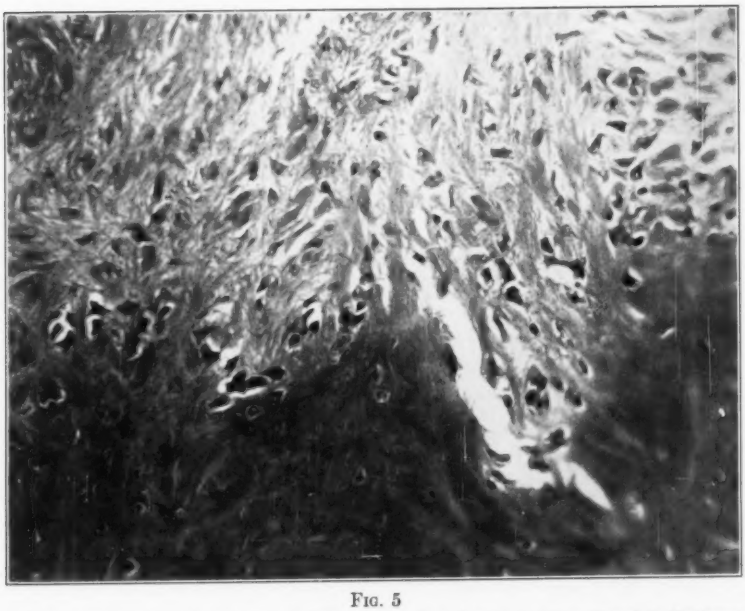

FIG. 5

High-power view of specimen in Fig. 4. Interface between zones 2 and 3. Collagen bundles are continuous between these zones and osteoblasts are active (hematoxylin and eosin, × 270).

FIG. 6

Fusion of fifth lumbar-sixth lumbar interspace at 120 days. Millipore (*M*) separates mass of matured reactive bone (*B*) from overlying fibrous tissue and muscle (*F*) (Mallory trichrome, × 50).

*C. Millipore:* The nylon fibers of the mesh used to reinforce millipore sheets were easily distinguished in polarized light. The plastic clearly divided the sections into a deep region, consisting of bone in various stages of development

and a superficial region of fibrous tissue and muscle (Fig. 6). Zones 1, 2, and 4 could be identified, but the region of granulation tissue, seen in sections of controls and labeled zone 3, was not identified. There was no bone formation above the millipore except in regions where a rent in the millipore membrane allowed intermingling of cells from the fusion plate and the overlying soft tissue (Fig. 7). In addition, a few sections demonstrated bone proliferation arising from viable laminar fragments raised with the periosteum at the time of operation.

Unlike the controls, the millipore-covered osseous fusion plates were as thick at thirty days as they were at 120 days. However, maturation of the reactive new bone to a more adult, trabeculated bone was progressive, and at 120 days was well advanced. The distance between the millipore membrane and the basal laminar layer predetermined the initial thickness of the fusion plate. The millipore-covered fusion plates at 120 days were judged to be slightly thinner than the 120 day control fusion plates, but no specific measurements were taken.

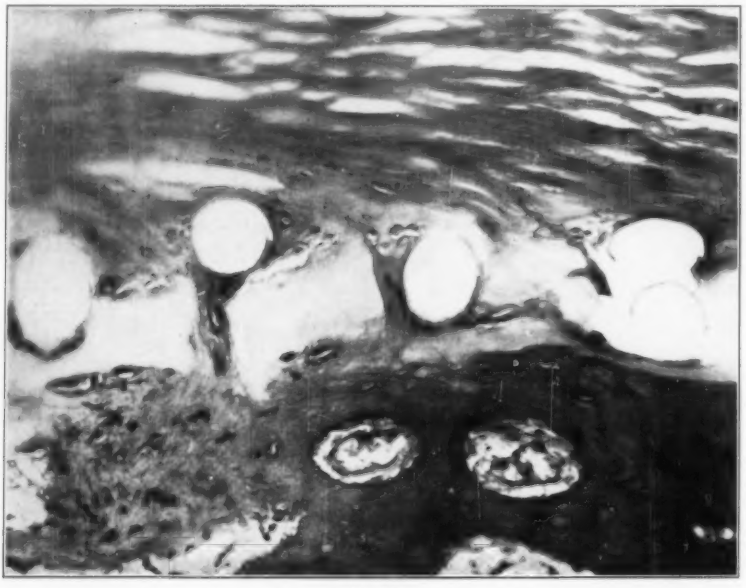

FIG. 7

Specimen similar to that in Fig. 6. Breaks in millipore can be seen. Note osteogenic cells in rents and outside in the superficial soft tissue (hematoxylin and eosin, × 220).

D. *Silastic:* Unlike the control and millipore specimens, the zone of new-bone formation (zone 2) was limited to a narrow area immediately adjacent to the laminae (Fig. 8). It was usual to find a distinct, large central area of fibrocartilaginous metaplasia and fibrous tissue. Along the narrow borders of the reactive new bone, a very distinct transition from bone to cartilage to fibrous tissue was frequently observed (Fig. 9).

The four zones previously described above could also be identified in sections from silastic-covered sections. However, zones 2 and 3 were much narrower than similar regions defined in sections of control fusions.

## DISCUSSION

This study was originally undertaken to determine the influence of overlying soft tissues on the progress of bone fusion in the dog's spine. Many of the results were not anticipated when the investigation was initiated. One of the most

FIG. 8

Fusion at fifth lumbar-sixth lumbar interspace covered with silastic after 120 days. There is a central and superficial area of fibrous connective tissue surrounded by a narrow band of new-bone formation (hematoxylin and eosin, × 3).

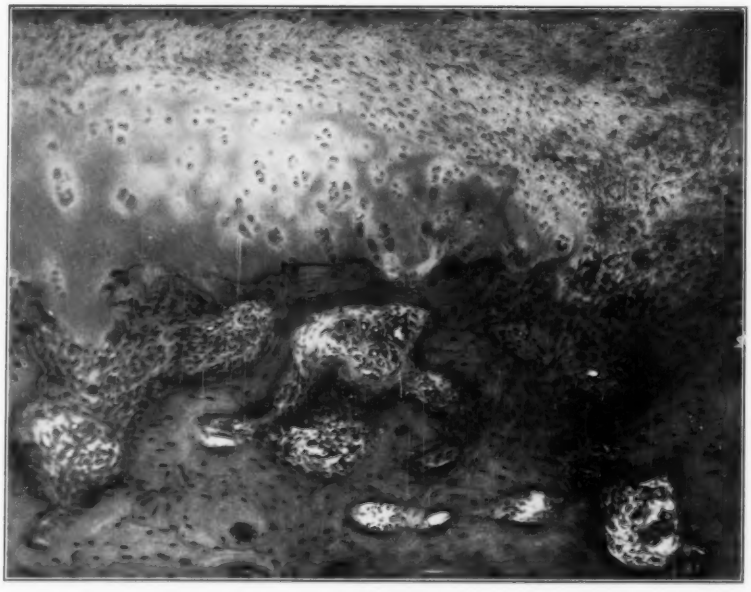

FIG. 9

High-power view of specimen shown in Fig. 8. Transition of bone to cartilage to fibrous tissue is demonstrated (hematoxylin and eosin, × 97).

striking of these was the complete failure to obtain successful fusion at the seventh lumbar-first sacral interspace, regardless of the method used. Had this result been foreseen, the early phases of the experiments would not have been planned so that each animal with two fusion sites at the fifth lumbar-sixth lumbar and seventh lumbar-first sacral interspaces might serve, to a degree, as its own control. In retrospect, a detailed analysis of the mechanics of the canine spine might have been helpful. First, the dog has seven lumbar segments with the lumbosacral articulation occurring at the seventh lumbar-first sacral level. The seventh lumbar segment is extremely mobile in respect to the first sacral segment. Facets are in the sagittal plane, allowing not only a large degree of flexion-extension, but also a great amount of lateral movement. It would seem that excessive motion was probably the most important factor in producing complete failure at the lumbosacral junction.

If the failure rate at the lumbosacral junction was unanticipated, so too was the result of using silastic as an interposition membrane at the fifth lumbar-sixth lumbar level. In all animals treated in this manner there was failure of fusion, and a uniform histological picture of ineffective osteogenesis was seen. These findings are in stark contrast to those obtained when millipore was used at the fifth lumbar-sixth lumbar level; in all animals thick, solid bone-fusion masses were produced. The main difference between these experimental circumstances is the permeability of the interposed membrane.

Millipore is an extremely porous and inert cellulose acetate plastic. The pore size, which in the HA formulation measures a maximum of 0.45 micron, is sufficiently small to prevent the transmigration of cells while permitting free diffusion of extracellular fluids. The results of its use in neural regeneration [2,4] and embryonic induction [7] suggested that it might prove a valuable tool in studies of osteogenesis. Silastic, on the other hand, although also quite inert in tissues, is impermeable to both cells and tissue fluids.

It seems from this research, that differences in results between the fifth lumbar-sixth lumbar fusions covered with millipore and those covered with silastic may be largely attributed to the amount of tissue fluids diffusing through these interposed membranes. If this is the case, then one major role of the soft tissues in osteogenesis is to serve as a source of nutrition for migrating osteoblasts. Under the silicone membrane, new-bone formation was scanty, being limited to those areas immediately adjacent to decorticated laminae. Immediately next to the layer of new bone, tissue resembling hyaline cartilage was found. This in turn blended into a zone of fibrocartilage and then into a massive area of dense fibrous tissue. This pattern of transition from bone to fibrous tissue suggested that the farther one progressed from the decorticated lamina, the more likely one was to encounter non-osseous material.

Many studies in the past have indicated that nutritional and other environmental circumstances determine, to a large degree, the manner in which a cell may behave. It has been proposed that the same cell can make both cartilage and bone, depending on the oxygen concentration [8]. Recent studies have indicated that there may be an optimal oxygen concentration for the production of bone, and that cells arising from adult skeletal muscle can produce cartilage, preosseous, and fibrous tissue *in vitro* [1]. In view of these observations, it seems reasonable to postulate that many cells migrating from the osseous bed may outstrip their proliferating blood supply [8,10]. Since all nutrition at the cellular level is derived from extracellular fluids, a cell that wanders any distance from its blood supply may become starved. Osteoblasts or pleuripotential fibroblasts, when robbed of tissue fluids by silastic, may find their nutritional environment inadequate to support production of osseous matrix so that they produce a cartilaginous or fibrous-tissue matrix instead.

There was no evidence from this study that bone-forming cells elaborated a diffusible substance capable of influencing undifferentiated connective-tissue

cells in the overlying soft structures to produce bone. It must be emphasized that several factors should be considered when evaluating this evidence. First, Grobstein reported that no positive induction results were obtained in many of his studies when membrane thicknesses were greater than twenty-five micra. The millipore used in these experiments was 150 micra thick, since thinner, unreinforced millipore sheets were impractically fragile. However, the flow-rate of such material is adequate to permit good cell nutrition [2], and it seems unlikely that diffusible substances did not pass equally well in both directions across the membrane. It is conceivable that diffusible inducer substances may be active over limited distances and may affect only young, undifferentiated cells. By the time proliferating osseous tissues had traversed the distance from the laminae to the millipore, a sufficient period had probably elapsed for a mature membrane to have been formed between the soft tissues and the millipore. Under such circumstances, the resulting cells of differentiated tissue may not have been capable of responding to an osteogenic stimulus.

Several observations were of interest when the control and the millipore covered fifth lumbar-sixth lumbar fusion specimens were compared. In general, the fusion plates were thicker and more uniform in the millipore animals at thirty days than the controls. This finding may account for the fact that in only seven of ten control animals were fusions judged solid by our gross criteria, as opposed to twelve out of twelve of the millipore animals. However, of four controls sacrificed at thirty days, there was motion in three. If it is logical to charge that this is much too early to expect solid fusion, it is also logical to ask why then were fusions in five out of five animals in which millipore was used solid by the same criteria at thirty days? The answer seems to center on the observed differences in size and uniformity of the fusion mass in the early stages of osseous repair. The control animals gave evidence that active osteogenesis continued over the entire 120 days of the study, gradually thickening the fusion plate and eliminating areas of fibrous tissue. Only after this period was the mass as thick as that of the thirty-day millipore specimens. In this light, the millipore functioned not only as a permeable membrane, but also prevented the overlying, differentiated soft tissues from encroaching on the area of new-bone formation. In this manner, a space was created and maintained into which proliferating bone could rapidly grow.

These results reinforce Berg's theory and confirm Murray's findings that new bone formed within perforated plastic cages placed next to raw cancellous bone. The apparent discrepancy between the results of this study and those of Hellstadius probably stems from the differences in operative sites. It seems logical that the osteogenic response of the raw cancellous bed will be much greater than that of a roughened cortical bed.

Many of the findings in this study raise more questions than they answer, and have suggested additional lines of research. In addition, they reinforce many of the concepts currently of use in spine fusions at the clinical level. The importance of providing an environment that will favor the early production of an abundant quantity of osteoid seems clear. A maturing mass of callus would seem to be more effective in limiting motion between adjacent spinal segments than most local appliances or immobilization of the patient himself.

In addition, these results amplify the concept that a large outgrowth of osteogenic cells from bone can, under favorable environmental circumstances, produce abundant new bone. Most of this arises from the laminae, little coming from the autogenous chips at the fusion site. The chips, however, serve an integral function for they, by virtue of their mass, elevate the differentiated soft tissues from the osseous bed, and provide a potential space for new-bone formation. However, the addition of excessive quantities of bone chips or massive sheets of cortical bone may be detrimental, if they act to limit diffusion in the same manner as silastic.

## CONCLUSIONS

1. The soft tissues overlying the spine-fusion mass probably constitute a critical source of nutrition for the cells participating in the early phases of osteogenesis.

2. HA millipore, 150 micra thick, does not transmit active osteogenic inducer substances, if such substances do, in fact, exist.

3. The primary impetus for osteogenesis in a spine-fusion site arises in the osseous bed. The overlying muscle may serve to shape both the quality and quantity of the fusion mass.

4. Motion, playing its well recognized role in pseudarthrosis formation, probably accounted for the complete failure of fusion in the dog's lumbosacral joint.

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## REFERENCES

1. BASSETT, C. A. L.: Unpublished data (1959).
2. BASSETT, C.A. L.; CAMPBELL, J. B.; and HUSBY, JAKOB: Peripheral Nerve and Spinal Cord Regeneration: Factors Leading to Success with a Tubulation Technique Employing Millipore. Exper. Neurol. (in press), 1959.
3. BERG, ATLE: Contribution to the Technique in Fusion Operations on the Spine. Acta Orthop. Scandinavica, **17:** 1-30, 1947.
4. CAMPBELL, J. B., and BASSETT, C. A. L.: The Surgical Application of Monomolecular Filters (Millipore) to Bridge Gaps in Peripheral Nerves and to Prevent Neuroma Formation. Surg. Forum, **7:** 570-574, 1956.
5. CAMPBELL, J. B.; BASSETT, C. A. L.; HUSBY, JAKOB; and NOBACK, C. R.: Axonal Regeneration in the Transected Adult Feline Spinal Cord. Surg. Forum, **8:** 528-531, 1957.
6. GOMORI, GEORG: Histochemical Specificity of Phosphatases. Proc. Soc. Exper. Biol. and Med., **70:** 7-11, 1949.
7. GROBSTEIN, C.: Trans-filter Induction of Tubules in Mouse Metanephrogenic Mesenchyme. Exper. Cell. Res., **10:** 424-440, 1956.
8. HAM, A. W., and HARRIS, W. R.: Repair and Transplantation of Bone. Chap. 16. *In* The Biochemistry and Physiology of Bone. Edited by Geoffrey H. Bourne. New York, Academic Press Inc., 1956.
9. HELLSTADIUS, ARVID: Study on the Formation of New Bone. Acta Orthop. Scandinavica, **20:** 89-93, 1950.
10. HIBBS, R. A.: An Operation for Progressive Spinal Deformities. New York Med. J., **93:** 1013-1016, 1911.
11. HIBBS, R. A.: An Operation for Pott's Disease of the Spine. New York State Med. J., **12:** 501-504, 1912.
12. HOWORTH, M. B.: Evolution of Spinal Fusion. Ann. Surg., **117:** 278-289, 1943.
13. LILLIE, R. D.: Histopathologic Technic and Practical Histochemistry. New York, McGraw-Hill Book Co. Inc., 1954.
14. MCLEAN, F. C., and URIST, M. R.: Bone: An Introduction to the Physiology of Skeletal Tissue. Chicago, University of Chicago Press, 1955.
15. MURRAY, GORDON; HOLDEN, R.; and ROSCHLAU, W.: Experimental and Clinical Study of New Growth of Bone in a Cavity. Am. J. Surg., **93:** 385-387, 1957.
16. WILLIAMS, R. G.: A Study of Bone Growing from Autografts of Marrow in Rabbits. Anat. Rec., **129:** 187-200, 1957.

## DISCUSSION

DR. JOHN H. MOE, MINNEAPOLIS, MINNESOTA: The authors present evidence that spine fusions covered with millipore, a membrane permeable to tissue fluids but impermeable to cells, showed a higher percentage of early solid fusions than was obtained by similar fusions covered with a membrane impermeable to both fluids and cells. Eliminating all of the unsatisfactory fusions done at the lumbosacral joint level, there were twelve fusions attempted with millipore covering, all of which fused solidly, compared with ten fusions covered with impermeable silastic, none of which fused. They found that a control series of ten similarly performed fusions with only soft-tissue coverage resulted in failure in three of these. This is not a large series of spine fusions.

The authors found that the fusions covered with millipore were definitely thicker after thirty days than were the control series. They found no evidence of fibrous tissue under the millipore. They concluded that all new-bone formation originated from the decorticated laminar surfaces and that there was no evidence of induced bone formation in the soft tissues beyond the millipore membrane. They further concluded that the soft tissues adjacent to

*(Continued on page 1266)*

# Treatment of Bone and Joint Tuberculosis in Children

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## BASIC FACTS

In examining candidates for the American Board of Orthopaedic Surgery, the question is frequently asked, "What single factor influences one's decisions most in the treatment of children as compared with adults?" Of course, the answer is growth; growth in size, in length of parts, and in total height, together with maturation of all tissues. Not merely is there growth in size, but fully as important, there is the development of structures in many directions. Maturing of structures of the body, rearrangement of internal and external configuration, decrease of resiliency and elasticity of the parts, and increase in strength and rigidity are only some of the alterations that occur as the child becomes the adult.

A second important factor which drastically alters the orthopaedic treatment of children as compared with the treatment of adults is the amazing tendency inherent in children's tissues to repair. This capacity for spontaneous repair is entirely separate from the growth potential, yet frequently the two seem to combine to produce surprisingly favorable results. The influence of both of these factors must be taken into consideration by any physician treating children.

Since this paper is limited to the treatment of destructive lesions of the osseous and articular systems, both of which are very susceptible to growth disturbance, at the same time having great potentialities for reconstruction by repair, we shall have to keep these factors strictly in mind in the subsequent paragraphs.

## PREVENTION

Obvious as it may be, one must again and again return to the fact that the prevention of a tuberculous lesion, especially the primary complex, is much more desirable than the cure. In this connection it is of interest that within the author's lifetime, the child's chances of avoiding these terrible lesions have increased tremendously as have those of the general population due to sanitary measures directed toward control of the dissemination of this disease through the medium of food, milk, or water. The elimination of congested living conditions and the control of infected carriers of the disease have produced definite beneficial results. Such measures alone have been shown sufficient to totally eliminate this disease in cattle. Unfortunately, in the human race the drastic extent of such measures employed for cattle cannot be carried out so as to make prevention completely effective. With the advent of the use of streptomycin in the treatment of tuberculosis, the prevention of tuberculosis became more effective both for children and for the general population due to the removal of some of the potential carriers who might transmit the infection. Much more positive prevention became possible with the advent of the nicotinamides.

Two further facts have a favorable influence in the prevention of this disease in children as compared with adults. In general, if food and clothing are scarce the child will have them even though the family goes without. Where conditions warrant it the child can be removed by court order from the home and placed in an environment where there will not be exposure to infection. This preventive

measure is difficult to put in effect and is accomplished nowhere near as frequently as it should be.

## BASIC PATHOLOGY

Tiresome as it may be, we must review the basic pathological facts as we see them. Treatment of the bone and joint lesions must always be secondary to the treatment of the primary focus in the lungs or lymph glands. Tuberculous bacteraemia must have taken place before the onset of the bone lesions. It is of only theoretical importance whether this bacteraemia occurred with the initial seeding which caused the primary complex or later from the primary complex [7]. Why only solitary areas of active foci of disease develop after such a widespread seeding is but little understood. Granted that embolic localization of bacteria occurs in bone or joint, the first microscopic finding is one of a typical giant cell surrounded by histiocytes (epithelioid cells). There is considerable difference of opinion as to whether the histiocytes degenerate and form the giant cell, or whether the giant cell forms first and is surrounded by histiocytes. This would appear as insoluble. In any case, coagulative necrosis occurs within the giant cells and their destruction and coalescence with other similar microscopic lesions produce a caseous necrotic center which gradually increases in size with endarteritis and periarteritis of the vascular structures coursing through the area. Denervation of the area is caused by perineural fibrosis, by compression destruction and lysis of the neural structures, as well as by the stripping of the nerves from osseous and joint structures. The final stage of the destructive process is liquefaction of the detritus of the destroyed tissue which is enhanced by fluid from surrounding irritated living structures. Further damage to surrounding tissues is produced by the mechanical dissection of the abscess which results. By its size, its pressure effect, and its stripping action it destroys structures not already involved in the disease process robbing these of blood supply as well as innervation. Disregarding the presence of active tuberculous organisms, such a lesion, due to its size and to its contained, irritating, secondary products, poses a considerable problem with respect to management and control. In the presence of infection by the *Mycobacterium tuberculosis* (the Red King), the problem of control has in the recent past proved almost insurmountable. The one thing that makes the difference between success and failure in treating this lesion at the present time as compared with the past, is the ability to control and destroy the tuberculous organism. As regards children, however, many other interesting facts must be appreciated before treatment is considered.

Tendon-sheath and fascial infections are rare in children, except when secondary to bone or joint involvement. Although discrete synovial involvement is more common in the adult, it is more fulminating in its course in children. Joint inflammatory changes frequently occur which are sterile for the tuberculous organism and secondary to nearby undisclosed or unsuspected bone foci. It is not unusual in a child to see a swollen knee of considerable extent associated with a tuberculous lesion in the lower portion of the femur, upper portion of the tibia, the patella, or the upper portion of the fibula which has not yet broken through and involved the joint. In such lesions, even in the pre-antibiotic era, accurate diagnosis and surgical evacuation of the bone focus frequently resulted in aborting the disease and salvage of a joint apparently doomed to destruction. These represent the tuberculous joints which, in the past, were preserved intact and cured by surgery with maintenance of function.

Tuberculous osseous involvement in children, while exhibiting the same microscopic picture as in adults, produces many clinical and roentgenographic changes which are different from those found in the fully developed skeleton. Some of the variations occurring in the child as compared with the adult are extreme and bizarre while others, although definite, require critical evaluation to be appreciated. These differences are based upon the histological structure of the

FIG. 1-A FIG. 1-B FIG. 1-C

Fig. 1-A: Roentgenogram shows spina ventosa with expansion of the soft cortex in a long bone and a short bone of a child.
Fig. 1-B: Appearance of erosion of the metaphysis due to tuberculosis.
Fig. 1-C: In the epiphysis, tuberculosis usually causes sequestration in the child.

child's bone as compared with that of the adult. A child's bone has extreme vascularity, soft cortex, highly reticulated marrow, compact metaphyseal area, an epiphyseal growth plate, and epiphyses which are highly susceptible to vascular isolation. Another factor not so commonly appreciated, is that the child's bone shows very little age necrosis. Evidence has been provided that as bone ages there is an increasing proportion of non-viable structure awaiting removal and replacement by living bone [6,8,10,11]. This factor seems to be of import in explaining some of the differences in appearance of the bone which is being destroyed by the tuberculous process in children as compared with that in adults.

The appearance of tuberculous lesions in the long bones seems to differ from that in the short, round, and flat bones and in the spine. Actually such variations should be expected and are consistent with the normal histological structure of the child's skeletal system. If the diaphysis of a long bone is involved, considerable expansion of the whole diaphysis occurs as the result of the slow development of the disease. This expansion is due to the softness of the cortical structure in the child which is further weakened by the advance of the infectious lesion through the relatively vascular cortical bone. The appearance of so-called spina ventosa results. When the embolic localization occurs in the metaphysis, local destruction and erosion are seen. If the epiphyses are involved, sequestration in part or in whole is most likely to occur due to interruption of the blood supply (Figs. 1-A, 1-B, and 1-C).

In the short bones, involvement by the tuberculous process resembles that in the long bones in comparable regions, that is, in the diaphysis, metaphysis, and epiphysis. In the round bones the same expansive central lesion occurs as is seen in the diaphyses of long bones (Fig. 2).

In flat bones in children (skull and pelvis), lesions are characterized by total necrosis of the osseous structure leaving rounded punched-out areas. Vascularity, soft cortices, and lack of the necrotic cortical-bone structure which occurs in aging bone and which is not susceptible to disease attack, determine the nature and appearance of the lesion. In the adult such areas form sequestra, while in children this rarely happens (Figs. 3-A and 3-B).

Lesions of the vertebrae present the appearance and follow the course which one would expect after seeing the changes that take place in the other bone struc-

FIG. 2

FIG. 3-A

Fig. 2: Tuberculous osteomyelitis in a round bone in a child causes expansion and changes similar to those seen in long bones.

Fig. 3-A: In flat bones in children there is usually total destruction due to tuberculous involvement with no residual sequestrum.

Fig. 3-B: In the adult, sequestration is the rule and is dependent upon factors described in the text.

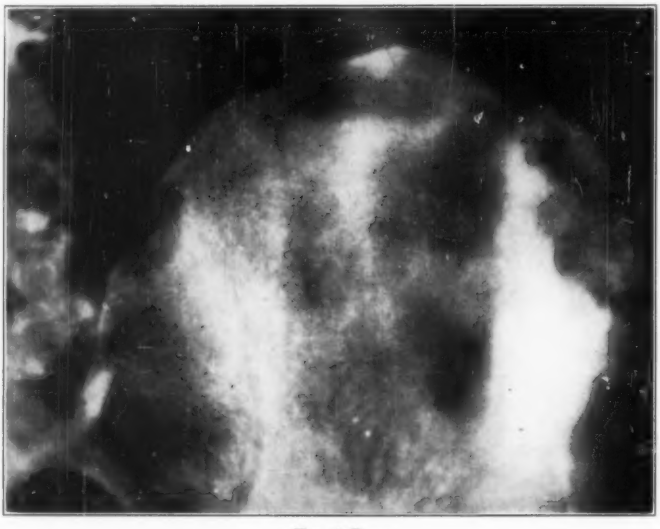


FIG. 3-B

tures. The vertebrae consist of a variety of bone structures. The vertebral bodies correspond to the round bones. The posterior elements are mainly cortical bone and, although rarely involved, they will, when posterior-element disease exists, respond in a manner similar to cortex elsewhere. One pictures the collapse of the vertebral body as being the onset of the lesion, but actually this is a late sequel. If seen early enough, horizontal expansion of the body can be detected (Fig. 4). Rarely does vertical expansion take place, since continued vertical compression of the spinal elements is present due to body weight. These forces of compression applied through the cartilaginous end plates prevent any vertical expansion. Occasionally, however, very early in the disease, some vertical expansion seems apparent. Frequently, anteroposterior expansion without collapse is noted. Collapse, when it does occur, is sudden, complete, and without the fragmentation of bone frequently noted in the adult (Fig. 5). The reason for this lack of sequestration or

FIG. 4

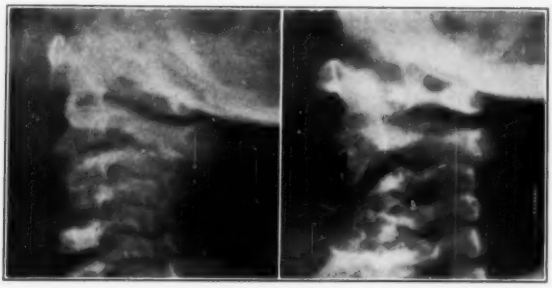


FIG. 5

Fig. 4: Vertebral bodies in a child behave in the same manner as round bones when affected by tuberculosis. At first there is expansion, limited above and below by the adjacent bodies.

Fig. 5: A tuberculous vertebral body in a child may have vacuolation occur of almost complete extent with sudden collapse thereafter. The changes in this child's cervical spine took place in less than twenty-four hours.

fragmentation in children is the apparent total disappearance of the internal vertebral body osseous structures of one or more spinal segments which results from the disease. This disappearance precedes the occurrence of collapse, a sequence of events which again can be predicted from the histological structure of bone in the young. If one accepts the concept that the dead bone structure which characterizes adult bone is not present in appreciable amounts in the child's vertebral body it is apparent that there is little bone in the child's vertebral body which will not be involved by the tuberculous process and be subject to total destruction except, of course, the peripheral cortical shell. In adult spines, sequestra, visible in both the roentgenogram and pathological sections, may remain to bind fragments together (Fig. 6). In children's spines, on the other hand, no such internal structure may persist. Hence, the central tuberculous lesion in the vertebral body in the child with an excellent blood supply from the periphery appears to almost completely destroy the centrum, somewhat expanding the cortical rim, which remains at first and gives the roentgenographic appearance of an intact vertebral body. While in this stage, there is very little to suggest the presence of disease. A few days later, almost total collapse may be apparent with no evidence as to where the destroyed bone has gone. Actually, the bone has long since virtually been replaced by disease products and granulation tissue. Some of this explanation is fact, and some is theory based on the observed changes. All of it puts the problem in its proper perspective, indicating the difficulty of arresting the lesion and developing the best mode of treatment to be applied.

Questions which are frequently raised are what happens to the intervertebral discs in tuberculous spondylitis and are the changes seen in the discs of importance? Our answers would be yes, the changes are important, particularly in children. In both the child and the adult the discs become necrotic and are sloughed from the surfaces of the contiguous diseased vertebral-body segments. In the adult they most frequently break up and are displaced. On pathological section only remnants can be found. In children they are similarly sloughed from the diseased osseous structures but they may also be partially liquefied and absorbed, the remnants being incorporated in the fibrous tissue of the repair process if the patient survives. Frequently, the remnants of the discs are still apparent between partially ankylosed healed vertebral-body segments (Figs.7-A and 7-B). In a recent study [5], we found persistent remnants of these structures visible in the roentgenograms made during an end-result study of children who had had arthrodesis of the spine done for tuberculosis after an average follow-up of twenty-one years. Until fragmentation of the disc occurs in the child (and this fragmentation seems to take place much later in children than in adults), direct union of involved

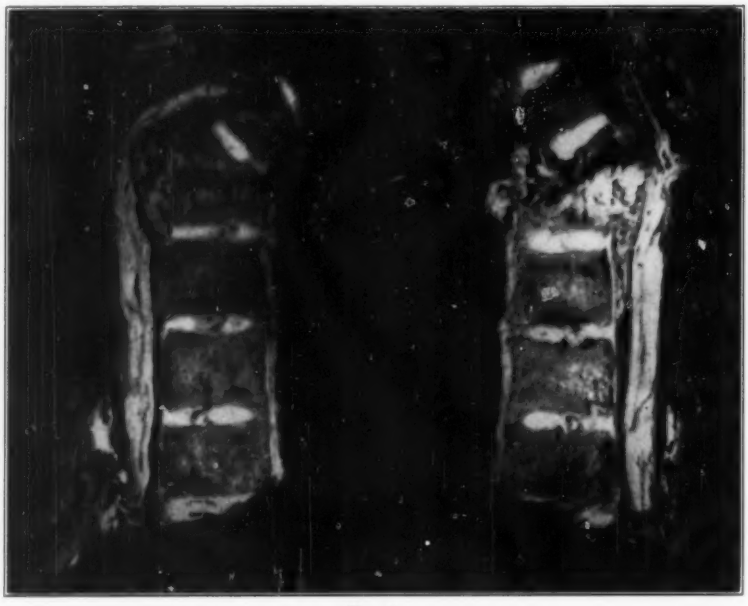


FIG. 6

In the adult spine involved by tuberculosis there are usually fragments.

FIG. 7-A

FIG. 7-B

In the adult (Fig. 7-A) and in the child (Fig. 7-B) disc remnants remain after even severe tuberculous infection. These may be ground up so that the roentgenogram may show no space, the fragments being extruded from the intervertebral area.

FIG. 8-A

FIG. 8-B

In tuberculosis of the spine, with collapse of the vertebral bodies, the posterior ligamentous structures are put on stretch and become ossified across the area of stress. They are not ossified throughout the end areas of disease, only through the areas of stress (Fig. 8-A). The same situation is seen in other structures where chronic stress is produced, such as the tendo achillis shown here (Fig. 8-B), in a fifty-eight-year-old patient with a club foot. Stress, not disease, is the causative factor. Since ossification does not occur throughout the area of disease, an extension of the spine fusion is frequently necessary beyond the kyphos.

vertebral bodies appears to be delayed with the result that the process of destruction and collapse continues for a longer time (except when surgical arthrodesis is accomplished).

Another pathological change seems to occur in tuberculous spondylitis in children which is not usually apparent in the adult. This is spontaneous ankylosis of the posterior elements over the area of most active disease collapse. This seems to result from changes in the mechanics of the spine at this level and does not seem to be a reaction to the disease process just anterior to it. When collapse of the vertebral body occurs, the posterior ligamentous structures are subjected to continuous stress. One must assume that degeneration of the ligamentous structures occurs incidental to this abnormal and continuous stress and that ossification follows in response to this degenerative process (Figs. 8-A and 8-B). The reason for assuming that this ossification is not in response to the disease process, *per se*, is that such spontaneous ankylosis, when present, is invariably limited to the area of maximum stress and does not extend throughout the full extent of the area where active disease is present. It was the presence of this spontaneous ankylosis in anatomical specimens of tuberculous spondylitis which suggested to Hibbs the original concept of fusion of the spine in advance of destruction [7].

## TREATMENT

Now that we have presented the magnitude of the destructive lesions encountered in bone and joint tuberculosis in children and have indicated the difficulties of visualizing the extent of involvement and the obstacles to be overcome we, at last, have a right to consider treatment. There was a time when gen-

eral measures were considered of supreme import, but this concept changed with the coming of the surgical era. Medicine provided no pharmacological substances of benefit. In days gone by it was not general physical measures, not surgical treatment, and certainly not medical treatment which achieved healing of such lesions. It was a fourth component of treatment which secured the favorable results obtained. This was time which produced gradual healing, at the expense of progressive deformity and advancing destruction of skeletal and arthrodial structures, albeit with constant uncertainty as to the recurrence of disease or the continuance of life itself.

Now, the order of importance of treatment has changed. Medical treatment is foremost with one antibiotic and two bactericidal agents which are effective. In 1945, streptomycin became available. This drug allowed at least partial control of the disease. As a result, time became extended. General physical measures involving the nutrition and the general care of the patient could now be provided before disaster struck. Surgery for the eradication of the diseased area and for the fixation of destroyed weight-bearing joints became safer and the results more satisfactory. Indeed, in certain patients who were so debilitated that surgical procedures could not be done, it was now possible to restore them to a condition at which point these procedures could be performed. However, with streptomycin this result was not achieved without paying a price. Since it was an antibiotic and prevented the production of the tubercle bacillus but did not necessarily destroy it, the action of this drug was not always consistently favorable. Resistant strains of bacteria were seen to develop. Certain toxicities caused highly undesirable sequelae, some of which were permanent. Where prolonged use of the antibiotic was necessary, the incidence of complications was 5 per cent total deafness, 20 per cent partial deafness, 12 per cent severe gastroenteritis (often necessitating discontinuance of the medication), and 3 per cent severe dermatitis [1]. At that time, we considered it a triumph in a child with a severe tuberculous bone or joint lesion to achieve a living patient even though deaf. We cannot agree to the acceptance of this complication now.

In 1951, isoniazid (Rimifon) and iproniazid (Marsilid) became available [2]. Fortunately, we began our experimental work with iproniazid. I say fortunately, since in the subsequent years comparable series of cases treated with isoniazid and iproniazid have shown that the latter, although more toxic, is much more effective in osseous and joint lesions [4]. The beneficial actions of iproniazid and its toxic reactions were recognized early. Some of these were adapted for the treatment of other non-tuberculous lesions. Many minor toxicities (about twenty) were recognized and have been reported [3]. Only two important toxic reactions remain to worry the physician. One, psychosis, rarely, if ever, occurs when dosage is maintained at a level of two milligrams per kilogram of body weight per day. In children, indeed, we employ three milligrams per kilogram of body weight per day unless personality changes take place. In the event that they do occur the drug is stopped for a few days and then begun at two milligrams per kilogram. I have never seen a true psychosis develop in a child. All personality and psychic changes have resolved following discontinuance of medication, or lowering of dosage. The other toxic reaction commonly feared is damage to the liver (hepatitis). We have never seen any evidence of hepatitis of any nature in a child on iproniazid. We have seen jaundice occur on occasion in adults, but this was not related to the iproniazid therapy. The most severe case of jaundice was in a patient with an obstructed common duct incidental to a retroperitoneal abscess. Drainage of the abscess relieved the jaundice and thereafter the patient was continued on iproniazid therapy without any evidence of liver damage. The few occasions on which we saw other evidence of jaundice were in patients who had had transfusions on one or more occasions and who were considered, on medical consultative advice, to have infectious hepatitis. In these patients iproniazid was stopped during the acute stage of hepatitis and in most of them renewed there-

FIG. 9-A

FIG. 9-B

Fig. 9-A: When destruction is not too great and control of the disease allows reformation of osseous parts, recovery without ankylosis can be secured in weight-bearing tuberculous joints (except the spine) with antituberculosis chemotherapy.

Fig. 9-B: Recovery interval in this roentgenogram is two years. The child has been followed an additional two and a half years without recurrence.

Fig. 10: When destruction is so great that portions of bone structure have been lost, even though the lesion is controlled by antituberculosis therapy, surgical reconstruction in the nature of ankylosis may be necessary to rehabilitate the patient.

FIG. 10

after, a close track being kept of the liver function. One patient we well remember had Laennec's cirrhosis. He was in desperate need of iproniazid and it was given. Very close attention was paid to liver function and no deleterious effects occurred from the iproniazid therapy, although it was maintained for several months.

As you will see, there has been a complete reversal of the order of the modes of treatment of bone and joint tuberculous lesions. Medicine now comes first with, in our opinion, iproniazid as the drug of choice. Second comes time, now provided safely by iproniazid. In addition, there may now be provision for eventual destruction of the tubercle organism in the body and perhaps eradication of the disease in the individual. This is a fact yet to be definitely proved. Third come the so-called general measures, nutrition, rest, splintage of parts, reduction of psychic activity and stress, and general physical care of the patient. Nowhere is heard that once resounding word *heliotherapy*. In the last place now appears surgery. This does not belittle its usefulness. It merely means that medical therapy has provided time which allows the general measures to improve the patient's condition so that such surgery as may be needed can be carried out. In childhood, treatment now provides a safe period of delay for observation of the first two factors discussed in this paper: growth and repair.

FIG. 11-A

Part of the lateral femoral epiphysis was sequestrated and the sequestrum fell out into the joint. Adequate chemotherapy in this child (three years old) enabled recovery from the disease and reossification of the defect with absorption of the sequestrum.

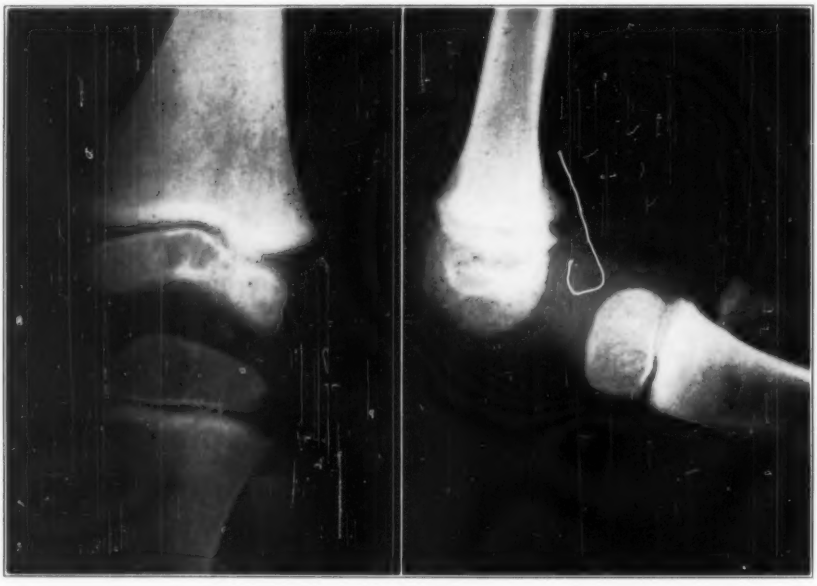


FIG. 11-B

Roentgenogram made seven months later. The child has been followed for seven years with no recurrence of the disease. There is no defect in the knee as to motion, growth, or stability.

Surgery still has an invaluable place in the management of these lesions. First among its indications is arthrodesis of the spine when any such lesion has been definitely established. We have shown that, in a child, total destruction in a

spinal lesion is impossible to delineate before collapse occurs. Prompt surgical fixation across the area of disease can prevent collapse almost certain to occur on a mechanical basis despite final arrest of the disease. The spine, however, in children is the only locale where we would advise immediate fusion. In all other joints, weight-bearing and non-weight-bearing, through use of the antituberculosis chemical iproniazid, time has been provided for a safe and prolonged period of observation as to the amount of reparative process which may take place. We have frequently been astounded by the repair that did occur in children (Figs. 9-A and 9-B). There are, of course, occasions in which joints badly involved are so destroyed as to be mechanically useless and deformed at a later date. When clear evidence of such deformity has finally become apparent, the disease process has been arrested by medication, and a reasonable period for natural repair has elapsed, arthrodesis in the weight-bearing extremity may be necessary (Fig. 10). Certainly, many arthrodeses in children are now avoidable (Figs. 11-A and 11-B), and in adults the same holds true although less frequently. A review of the results of treatment with streptomycin indicated that the percentage of success was nowhere near that obtained with iproniazid. Streptomycin had irreversible toxic effects, was much slower in its action, and allowed further destruction to take place as healing occurred. It could not be relied upon for sterilization of the focus and removal of the possibility of recurrence of the lesion at a later date to the same extent as the antituberculosis chemical.

Another use of surgery should not be forgotten. Biopsy of suspicious lesions is indicated and at an early date. Fear of breakdown of the biopsy incision need no longer deter one from such a procedure. Biopsy, if done, should be done before administration of iproniazid. Iproniazid should be started immediately after surgery.

How long should one continue the dosage of iproniazid? We have had many patients on this drug over a year. We have had numerous patients on the drug over two years. We have had an occasional patient on the drug three years and two patients we have kept almost continuously on this medication for a period of five years. We have seen no development of late toxic effects from prolonged medication. We do not know and cannot say when to stop medication. We would suggest in children that six months of medication after complete subsidence of all evidence of activity of the lesion by roentgenogram and on a clinical basis might prove sufficient. The age of the child will make a difference, as one would expect, remembering how speed of repair is increased by youth. In more severe and extensive lesions, since iproniazid is easy to administer, not expensive to buy, and since we have noted no permanent evidence of toxicity on prolonged use within the dosage limits given, perhaps it would be wise to err on the side of safety and continue medication much longer than we have stated.

## REFERENCES


1. Bosworth, D. M.; Della Pietra, A.; and Farrell, R. F.: Streptomycin in Tuberculous Bone and Joint Lesions with Mixed Infection and Sinuses. J. Bone and Joint Surg., **32-A**: 103-108, Jan. 1950.
2. Bosworth, D. M.; Wright, H. A.; and Fielding, J. W.: Marsilid in the Treatment of Tuberculous Orthopaedic Lesions (A Preliminary Report). Sea View Hosp. Bull., **13**: 52-73, 1952.
3. Bosworth, D. M.; Wright, H. A.; Fielding, J. W.; and Wilson, H. J.: The Use of Iproniazid in the Treatment of Bone and Joint Tuberculosis. J. Bone and Joint Surg., **35-A**: 577-588, July, 1953.
4. Bosworth, D. M.; Fielding, J. W.; Wilson, H. J.; Guzman-Acosta, Manuel; and Demarest, L. M.: A Comparison of the Efficacy of Iproniazid (Marsilid) and Isoniazid (Rimifon) in the treatment of Bone and Joint Tuberculosis. Sea View Hosp. Bull., **15**: 134-140, 1955.
5. Cleveland, Mather; Bosworth, D. M.; Fielding, J. W.; and Smyrnis, Panayiotis: Fusion of the Spine for Tuberculosis in Children. A Long-Range Follow-up Study. J. Bone and Joint Surg., **40-A**: 91-106, Jan. 1958.
6. Frost, H. M.: Personal communication.
7. Hibbs, R. A.: An Operation for Progressive Spinal Deformities. A Preliminary Report of Three Cases from the Service of the Orthopaedic Hospital. New York Med. J., **93**: 1013-1016, 1911.

8. Jaffe, H. L., and Pomeranz, M. M.: Changes in the Bones of Extremities Amputated Because of Arterial Vascular Disease. Arch. Surg., **29:** 566-588, 1934.
9. Milgram, Lillian: Skeletal Tuberculosis in Children Treated for Primary and Miliary Tuberculosis. Am. Rev. Tuberc., **75:** 897-911, 1957.
10. Mueller, W.: Über das Verhalten des Knochengewebes bei herabgesetzer Zirkulation und das Bild von Nekrose der Zwischenlamellen. Beitr. z. Klin. Chir., **138:** 614-624, 1926.
11. Sherman, M. S., and Selakovich, W. G.: Bone Changes in Chronic Circulatory Insufficiecy. A Histopathological Study. J. Bone and Joint Surg., **39-A:** 892-901, July 1957.

## DISCUSSION

### The Role of Soft Tissues in Osteogenesis

*(Continued from page 1254)*

the fusion played no part in osteogenesis other than acting as a source of tissue fluid nourishment.

It is always difficult to draw conclusions from a small series of experiments, but there can be little doubt that twelve of twelve solid fusions under millipore present a sharp contrast to the ten of ten pseudarthroses found in the fusions which were covered with impermeable silastic. Comparison with the control series is less impressive.

Failure of fusion in one or more areas of a long spine fusion often defies explanation when we know that each interspace has been done in the same careful manner. Absorption of the autogenous graft and its replacement by fibrous tissue is also a mysterious phenomenon. The authors have given us substantial food for thought. More work is required to substantiate the opinions which their experiments have brought forth. I agree with the authors that they have presented strong evidence to support the belief that an impermeable membrane over a prepared spine fusion bed inhibits osteogenesis and promotes production of fibrous connective tissue instead, while a membrane permeable to tissue fluids but not to cells, placed between the soft tissues and the fusion bed, seemingly promotes osteogenesis and inhibits the production of fibrous tissue.

Dr. Robert D. Ray, Chicago, Illinois: In evaluating an experiment of this type, one is faced with two problems: (1) have the authors established their results with the experimental methods employed and (2) are the proposed explanations of the results logical?

I believe Dr. Hurley, Dr. Stinchfield, Dr. Bassett, and Cmdr. Lyon have adequately established that spine fusion fails to occur in dogs if an impermeable membrane is used to separate muscles from the underlying bone but that fusion can occur if a permeable membrane is used. If one assumes that the membranes are inert, the explanation that cells developing from the bone bed outgrow their nutrition and require an additional medium for metabolic interchange seems reasonable. A third point is less firmly established: that fusion occurred more rapidly when a permeable membrane was used than when it was not. This raises the problem of biological variability, the theory of sampling, and the necessity of statistical evaluation of results. In this case the authors are dealing with a problem of comparative rates of healing and to establish their point would require groups autopsied at more frequent intervals.

An observation of interest from a basic standpoint is that cartilage and fibroblasts developed beneath the impermeable membrane whereas bone formed beneath the permeable membrane. This poses the question of the influence of environment on the differentiation of connective-tissue cells. The authors suggest that oxygen tension may be the important factor. Recent studies suggest that the partial pressure of carbon dioxide may be even more important. The observation that fibroblasts developed when the fusions failed has led the authors to speculate about the role played by fibroblasts in bone formation. I gather they concur with Ham who suggests that fibroblasts can differentiate from osteoblasts rather than the reverse.

The authors comment on the fact that bone failed to develop in muscle when it was separated from the osseous bed by the millipore filter. This raises the question of bone induction. Spemann coined the term *induction* to describe the influence of one tissue on the differentiation of a second, for example, the ventricle of the brain on the development of an optic lens from the overlying ectoderm. It would seem that intimate physical contact was an important aspect of the process. In this sense induction is an established phenomenon in bone formation as demonstrated by Huggins' beautiful experiments on bladder mucosa implants into muscle. The real question at issue is whether there is a specific inductor. Observations that bone may form in the kidney parenchyma following ligation of the renal artery, in muscle following injection of alcohol and alcohol and water soluble extracts of bone, in the eye following infections or the injection of formic acid, and the finding of ectopic bone around caseous tubercles and atheromatous plaques would lead one to suspect that it is not a specific process. If there is a common denominator in all of these phenomena—other than that the induced cell seems to be a primitive connective-tissue cell widely distributed in the body—it has not been proved as yet.

# Amputation as a Treatment for Certain Lower-Extremity Congenital Abnormalities

BY GEORGE T. AITKEN, M.D., GRAND RAPIDS, MICHIGAN

This study is presented as an objective evaluation of thirty-one patients with congenital abnormalities of the lower extremity who were treated by amputation. These patients were collected from all parts of the State of Michigan; their amputations had been performed in different communities and by different surgeons. They do not represent, therefore, a group of patients treated by one method according to a planned program. On the contrary, the method of treatment selected represents the decisions of several orthopaedic and general surgeons. In each instance the decision as to treatment was based on the merits of the individual case.

The abnormalities encountered in this series have been classified arbitrarily into six groups in order to permit more satisfactory understanding of the problem and the type of case involved. These classifications, or groups, in many instances do not indicate the full extent of the individual patient's abnormalities. To present detailed anatomical descriptions of each of these patients and to classify them accordingly would be verbose and serve no useful purpose. The classification of anomalies discussed in this series and their frequency are shown in Table I.

In the group listed as congenital kyphosis of the tibia are included all the patients with an anterior angular deformity in the distal half of the tibia and absence of the fibula. In addition to these anomalies there were alterations in the number of rays in the foot—only three being present as a rule—abnormal fusions of the tarsal bones, typical equinovalgus deformities of the foot, and, frequently, some abnormality of the distal tibial epiphysis.

The anomalies in the group just mentioned are representative of the abnormality that Harmon and, later, Coventry termed congenital absence of the fibula, and Badgley termed congenital kyphoscoliotic tibia. Coventry divided his cases into three groups, and the cases in this series are identical with his Group III. Badgley lists five types, and then adds other associated characteristics. The cases in the group considered here seem to be similar to his Type I, with some, but not all, of the associated characteristics. Harmon reported three cases of congenital absence of the fibula but did not classify them. The cases here reported are similar to his most severe case. Kite described this deformity, and presented the roentgenograms of cases similar to those in all the patients in this series. Thompson recently presented a similar series of patients, and he too named the deformity congenital absence of the fibula.

I use the term congenital kyphosis of the tibia because it seems to describe the most apparent clinical abnormality of the deformity and has been used on my service for many years to denote this deformity.

In the group classified as congenital abnormalities of the feet there are included all the foot anomalies which were not typically club-foot, with one exception. This patient had arthrogryposis with multiple abnormalities including the typical club-foot seen in arthrogryposis.

Among the cases classified as congenital pseudarthrosis of the tibia only typical examples are included. No case of pre-pseudarthrosis is included.

In the group classified as unknown abnormalities are all the cases in which insufficient documentary or roentgenographic evidence is available to permit a more satisfactory classification of the type of deformity that existed prior to amputation.

TABLE I

| Anomaly | No. of Cases | No. of Amputations |
|---|---|---|
| Congenital kyphosis of the tibia (congenital absence of the fibula) | 10 | 12 |
| Congenital abnormalities of the feet | 6 | 9 |
| Congenital pseudarthrosis of the tibia | 5 | 5 |
| Unknown abnormalities | 4 | 5 |
| Congenital absence of the tibia | 3 | 5 |
| Congenital abnormalities of the proximal end of the femur | 3 | 3 |

In those cases classified as congenital absence of the tibia, the name identifies the major abnormality present.

Among the cases classified as congenital abnormality of the proximal part of the femur are all the patients whose major deformity seemed to be a short femur with an abnormality of the proximal end. Characteristically, the head of the femur was within the acetabulum, but the neck was absent, and the proximal end of the deformed femoral shaft tapered down to a relatively sharp spicule which was riding high above the level of the acetabulum. One of these cases is a true congenital coxa vara, whereas the other two may represent different stages of coxa vara if one accepts Babb's classification.

There are thirty-one patients in the entire group—seventeen male and fourteen female—who had a total of thirty-nine amputations. This number includes the amputations of individual extremities, but not the reamputations at a higher level, which were done to revise the stumps of two patients. There were four above-the-knee amputations, six disarticulations of the knee, nineteen below-the-knee amputations, four disarticulations of the ankle, and six Syme's amputations. Because detailed operative notes on all these patients are not available, it has been impossible in some cases to determine whether a Syme's amputation or disarticulation of the ankle had been performed. The description of the amputation in the records available for survey has been utilized for classification, and therefore the designation, four ankle disarticulations and six Syme's amputations, is used although this may not be accurate.

## CONGENITAL KYPHOSIS OF THE TIBIA
## (Congenital Absence of the Fibula)

This was the largest single group of abnormalities of the lower extremity which could be readily classified in the series. There were ten patients—six male and four female—on whom twelve amputations were done. Two of the patients had bilateral, identical abnormalities, and both lower extremities were amputated. The amputations were performed by three surgical groups. The first group did six, and the other two did two amputations each. There were one above-the-knee, five below-the-knee, and six Syme's amputations. The Syme's amputations were performed on four patients, two of whom had bilateral procedures. One patient, fifteen years old at the time of his amputation, was the oldest patient on whom amputation was done in this group. The youngest patient, a female infant, was fifteen months of age at the time bilateral Syme's amputations were performed. The average age at amputation was 6.1 years. The follow-up in this group varied from four months to fourteen years.

In these patients the primary difficulty was excessive shortening of the leg, in addition to the difficulty in fitting satisfactory supportive footwear owing to the extreme equinovalgus deformity of the foot. A secondary problem was the unsightly appearance of the involved legs. Prior to amputation all of these patients had been fitted with various types of shoe lifts, corrective shoes, double upright braces, and in some instances, ischial weight-bearing braces. When an ischial weight-bearing brace was used, the extremity from the knee down was usually

encased in an open lacer leather cuff. The records indicate that the families were dissatisfied with the appliances utilized to produce equality of leg length and stability of the involved extremity. As the patients grew older, they complained about the appearance of the leg and the difficulty encountered in attempting to conceal the limb and apparatus, even when they were dressed. Only one patient in this group had had an osteotomy to correct the anterior angular deformity of the tibia; this osteotomy failed to heal. Several of the patients had had heel-cord lengthening in an attempt to place the foot in a proper weight-bearing relationship to the tibia; none of these procedures accomplished the desired reconstructive result.

### CONGENITAL ABNORMALITY OF THE FEET

Intrinsic bone abnormalities, malposition of the foot in relationship to the tibia, and variable elements of atavism, hypoplasia, and improper or abnormal segmentation of the rays are included in this group, as well as one case of severe equinovarus feet—the result of arthrogryposis. This group includes six patients—four male and two female—who had nine amputations. The longest period of follow-up was two and one-half years from the time of amputation. The age at which amputation was done ranged from eighteen years (the patient with bilateral club-foot secondary to arthrogryposis) to two years; the average age was 5.5 years. There were two knee disarticulations, five below-the-knee amputations, and two ankle disarticulations performed by four surgeons, one of whom operated on three patients.

### CONGENITAL PSEUDARTHROSIS OF THE TIBIA

In all of these patients the roentgenographic findings were typical, and some previous form of therapy had been attempted. Amputation was not carried out as a primary treatment in any of the five patients. One patient had not had prior reconstructive surgical care. There were five patients—one male and four female—in this group on whom five amputations were performed. The longest follow-up from the time of amputation was twelve years; the shortest follow-up was three months. The age at amputation ranged from eighteen years to three and one-half years. The average age at amputation was nine years. All five patients had below-the-knee amputations, which were performed by four different surgical groups.

### UNKNOWN ABNORMALITIES

The four patients classified under this heading had had amputations for congenital anomalies which were not well enough described—either in the records available or in correspondence with the operating surgeons—to permit us to classify them in any of the other groups. There were four patients—two male and two female—on whom five amputations were done. The longest follow-up from the time of amputation was fourteen years; the shortest follow-up was six months. The oldest age at which amputation was accomplished in this group was eleven years, the youngest was one day; the average age at amputation was 7.8 years. The procedures carried out in this group were one above-the-knee and three below-the-knee amputations and one ankle disarticulation. Three surgical groups performed the operations in this series of patients.

### CONGENITAL ABSENCE OF THE TIBIA

The preoperative diagnosis in these patients was congenital absence of the tibia, but the records are insufficient to determine what associated deformities were present. The group is comprised of three patients—one male and two female—who had five amputations. The longest follow-up from the time of amputation was sixteen years; the shortest follow-up was one year. The age at amputation ranged from five to three years; the average age was 4.3 years. The procedures performed were one above-the-knee amputation and four disarticulations at the

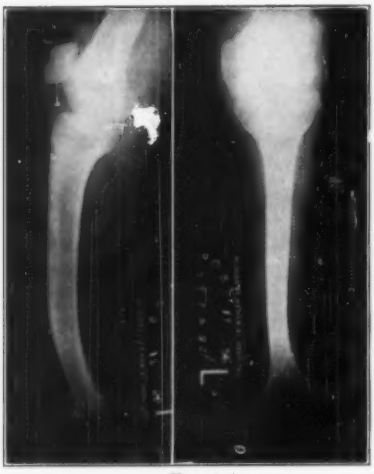


FIG. 1-A

FIG. 1-B

L. Y. Anteroposterior and lateral roentgenograms of both stumps. Note the complete absence of the fibulae. There is an angular deformity in the distal half of each tibia.

FIG. 1-C

FIG. 1-D

Fig. 1-C: The dimple in the skin at the apex of the angular deformity is clearly visible. These lower extremities are ideal below-the-knee stumps.

Fig. 1-D: The patient wearing conventional below-the-knee prostheses. There are leather thigh cuffs with lacers and willow stump buckets. The genu valgum is an intrinsic deformity and not the result of poor fitting.

knee. Two of these patients were operated on by one surgical group, and the third was treated by another surgeon.

### CONGENITAL ABNORMALITY OF THE PROXIMAL PART OF THE FEMUR

This deformity is described as an absence of the normal neck of the femur with upward displacement and abnormal shortening of the femur. There appears

to be failure of completion of rotation of the limb bud in all of these patients. This group includes three patients—two male and one female. The female patient had a true congenital coxa vara. Three amputations were performed on these patients; one of the amputations was revised at a slightly higher level. The longest follow-up was eleven years; the shortest follow-up was four years. The age at amputation ranged from twelve and one-half years to five years, with an average of nine years. One above-the-knee and one below-the-knee amputation and one ankle disarticulation were done by two surgical groups.

## CASE REPORTS

### *Congenital Kyphosis of the Tibia (Congenital Absence of the Fibula)*

R. M., a boy, born on December 29, 1946, was first seen when he was four months old. Roentgenograms showed an anterior angular deformity in the distal half of the tibia on the right, with absence of the fibula and an equinovalgus deformity of the foot. As the boy grew older he attempted to stand, at which time an effort was made to fit him with a satisfactory supportive appliance on the right side. A shoe with a cork lift to accommodate for the shortening, with various types of braces including a short caliper brace, a long caliper brace, and finally, an ischial weight-bearing brace with an open lacer cuff, were tried. The cuff was necessary to keep the heavy shoe and brace on the extremity in the presence of the severe equinovalgus deformity of the foot. No corrective surgery was attempted. This boy had a three-inch discrepancy in leg length, and on May 12, 1950, when he was three and one-half years old, a right below-the-knee amputation was done. Within two months after operation the patient was fitted with a standard below-the-knee prosthesis. The boy, now ten years old at the time of writing, has been followed regularly and is considered to have a good functional result—he is in the proper grade at school and engages in normal activities. The mother said that if she had known that the boy could have been made this comfortable, she would have had the amputation done earlier.

L. Y., a young man, born on May 13, 1938, had, according to the records, bilateral congenital abnormalities of both feet characterized by absence of two rays, fusions of the tarsal bones, absence of the fibula, and anterior angulation of the tibia in the distal half. In July 1948, when the boy was ten years old, he was having such difficulty with his appliances that ankle disarticulations (Syme's) were done. Roentgenograms made after operation showed congenital kyphosis of the tibia. Three months after operation this patient was first seen in the out-patient amputee clinic and since that time he has been followed regularly. The patient is an excellent walker and is fully and normally active. At the time of writing he is eighteen years of age and is considered to have a satisfactory functional result (Figs. 1-A through 1-D).

J. W., a girl, was born on September 9, 1951. Her records describe her as having an anterior angular deformity in the distal half of both tibiae and deformities of the feet which are not clearly described. Bilateral Syme's amputations were done when the child was fifteen months old; three months after operation she was seen in the out-patient amputee clinic and found to have the residuals of bilateral congenital kyphosis of the tibiae with Syme's amputations and flexion contracture of the left knee amounting to about 30 degrees. The patient was fitted with standard below-the-knee prostheses and when last seen she was fully ambulatory, although the flexion deformity of the left knee was still uncorrected. This interfered with the smoothness of her gait, but did not interfere with her ability to get around.

J. W., a young man, born on May 12, 1936, was first seen when he was two months of age, at which time he was found to have deformities of both feet with a rather severe anterior angular deformity in the distal half of the right tibia and only three rays in the right foot. The patient was followed until he was fifteen years of age, when a right below-the-knee amputation was performed because of severe shortening of the right leg and difficulty in getting a satisfactory shoe. The patient has been seen regularly for the five years since amputation; he is a normally active boy for his age and is satisfied with his result. At the time of operation there was a nine-inch difference in leg lengths (Figs. 2-A through 2-D).

D. L., a young woman, born on January 1, 1940, was first seen when she was two months old and has been seen regularly since. Roentgenograms of the patient showed typical congenital kyphosis of the tibia, absence of the fibula, fusion of the tarsal bones in the posterior part of the foot, and an equinovalgus deformity. Because of increasing shortening and difficulty in getting satisfactory footwear, a right below-the-knee amputation was done on May 25, 1951. At this time there was a difference of four inches in the length of her legs. The patient has been followed since surgery, and has a satisfactory functional result.

K. B., a girl, was born on December 3, 1950. Roentgenograms made in another institution

FIG. 2-A

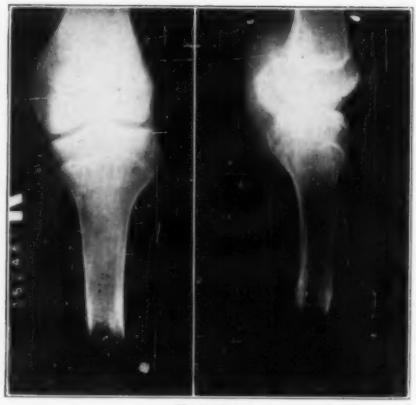


FIG. 2-B

Fig. 2-A: J. W. Roentgenograms showing anterior angular deformity of the tibia in its distal half, absence of the fibula, talocalcaneal fusion, and only three rays in the foot.

Fig. 2-B: Anteroposterior and lateral views of the stump. A below-the-knee amputation rather than an ankle disarticulation was done on this patient.

FIG. 2-C

FIG. 2-D

Fig. 2-C: The below-the-knee stump is short and shows some valgus deformity. (It is possible that an ankle disarticulation would have been better for this patient.) Experience has shown that the angular deformity of the tibia can be well accommodated in a prosthesis.

Fig. 2-D: The patient is wearing a conventional below-the-knee prosthesis and, despite the short stump, does not need a slip socket.

showed that prior to amputation this patient had an acute angular deformity in the distal half of the left tibia, with an associated abnormality of the posterior part of the foot and a decreased number of rays in the foot. A Syme amputation on the left was performed on March 23, 1953. Within three months after surgery the child was seen in the out-patient amputee clinic and was fitted with a classic below-the-knee prosthesis with which she rapidly learned to walk. During the course of follow-up the child has been active and is considered to have a satisfactory functional result.

T. B., a boy, born on July 12, 1949, was first seen when he was three and one-half years old. At that time he had classic congenital kyphosis of the tibia with absence of the fibula, a three-rayed foot, and deformity of the tarsal bones in the posterior part of the foot on the affected side. Amputation had been recommended, but the mother was reluctant to accept this suggestion. The child was walking with crutches. Cumbersome shoes with lifts and braces were unacceptable. After detailed discussion of the situation with the mother, when the patient was four years old, a right below-the-knee amputation was done on July 18, 1953. At the time of surgery there was a shortening of three inches on the affected side. Within three months after operation, the patient was fitted with a standard below-the-knee prosthesis, and has been followed in the out-patient clinic since then. He is considered to have had a satisfactory functional result.

G. B., a boy, born on December 20, 1954, was first seen when he was ten months old. Roentgenograms showed an angular deformity of the right tibia in its distal half, absence of the fibula, an equinovalgus deformity, and a reduction in the number of rays in the foot. Because of previous experience with similar deformities, amputation was recommended as a primary procedure. The family was reluctant to accept this but finally consented and on October 3, 1956, a right Syme amputation was done. At this time there was two and one-half inches of shortening of the affected extremity. This patient has had a limited follow-up, but at the time of writing he is ambulatory in a prosthesis.

F. M., a man, born on August 8, 1931, was first seen when he was one year old and has been followed for twenty years. Early roentgenograms were reported to show absence of the fibula with an angular deformity in the distal half of the tibia. Various types of braces and elevated shoes were used until August 1940, when the boy was nine years old, at which time a right below-the-knee amputation was done. During the ensuing twelve years of follow-up the patient has shown a satisfactory functional and cosmetic result. This is the one patient in the series who had an osteotomy of the tibia and in whom non-union developed at the site of osteotomy.

P. L., a man, born on April 14, 1931, was first seen at sixteen months of age, when he was found to have an anterior angulation of the left tibia. No preoperative roentgenograms or pictures of this patient are available, but the record clearly describes a three-toed foot with equinus and valgus deformity. Initially, the patient was fitted with a short brace and shoe and appropriate lift. On August 17, 1942, when the patient was eleven years old, an above-the-knee amputation on the left was done. He was then fitted with a pylon prosthesis—an acceptable practice at that time. In July 1948, however, this patient was fitted with a standard suction-socket above-the-knee prosthesis and became a good wearer with excellent function. In a letter dated July 1956 the patient wrote that he was employed as a school teacher and was normally active and without complaints.

### *Congenital Abnormality of the Feet*

G. W., a woman, born on March 4, 1934, was first seen when she was six weeks old, at which time a diagnosis of arthrogryposis was made. She was found to have severe bilateral talipes equinovarus, congenital dislocation of both hips, and limitation of motion in both knees and one elbow. Multiple reconstructive procedures were performed on her feet, including heel-cord lengthenings, plantar fasciotomies, and reconstructive procedures on the tarsal bones. Open reductions of both hips were unsatisfactory; a false acetabulum developed on the right, and very little acetabulum formed on the left. When the patient was eighteen years old she requested bilateral below-the-knee amputations in the hope that she might have more satisfactory feet. A below-the-knee amputation was performed on the left in February and on the right in August of 1952. The patient was followed until October 1954, at which time she was married and was normally active as a housewife.

E. J., a young man, born on January 7, 1940, was operated on in 1942 at another hospital where a congenital abnormality of the left foot was removed. From the mother's description, the child apparently had an atavistic, hypoplastic remnant of the left foot which served no useful purpose and was removed so that he might have a proper stump for the application of a prosthesis. The child was fitted with a conventional below-the-knee prosthesis and during the last ten years has been able to ice skate and play basketball and some football, as well as

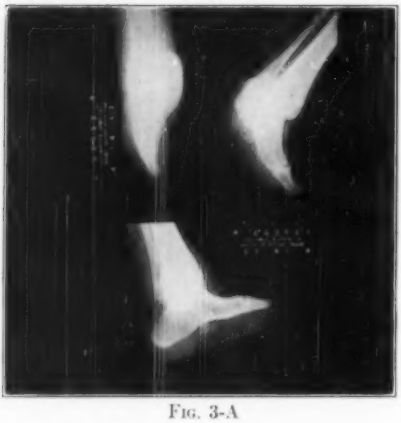


FIG. 3-A

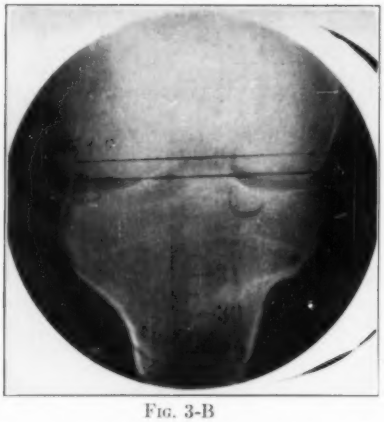


FIG. 3-B

Fig. 3-A: K. J. Anteroposterior, lateral, and oblique roentgenograms of the congenitally deformed right foot. There was a sensory deficit in this foot which, with weight-bearing, permitted the development of trophic ulcers.

Fig. 3-B: Anteroposterior roentgenogram of the amputation stump. This stump is almost too short, but the sensory changes in the leg necessitated amputation at this level.

FIG. 3-C

FIG. 3-D

Fig. 3-C: The patient walks well in her standard below-the-knee prosthesis and the slip socket. In this instance salvage of the knee was extremely advantageous to the patient.

Fig. 3-D: Note the short stump and the slip socket on the prosthesis.

carry out the other normal activities of school life. The stump required one revision for overgrowth of the tibia; this was done in June 1954. A typical talipes equinovarus on the contralateral side was treated conservatively with a good result.

K. J., a young woman, born on August 4, 1941, was reported to have had multiple congenital abnormalities involving both hands and feet. The hands showed, primarily, syndactylism with hypoplasia of the rays. In the left foot there was a mitten-like deformity involving all but the great toe. On the right side the leg was short from the knee down, with the foot

presenting the external appearance of a congenital Chopart amputation. This patient also had loss of sensation in the distal two-thirds of the right leg. Attempts to fit this girl with a slipper-type prosthesis and a shoe were not successful because of the great mechanical instability of the prosthesis, which made it difficult for the patient to keep the prosthesis on. Owing to the sensory disturbances in the foot trophic ulcers developed on the plantar aspect of the foot; this condition necessitated long periods of time without weight-bearing on the involved limb. Because of the increasing frequency of trophic ulcers, a right below-the-knee amputation was performed in July 1954. It was necessary to amputate high on the tibia at a level where the skin sensation was normal to superficial testing. Although amputation at this level did not give an ideal length of stump, it was considered necessary because of the sensory changes. The patient was fitted with a below-the-knee prosthesis with a slip socket added to accommodate for the short stump. The patient has been followed since amputation and is currently under active supervision in the out-patient clinic. She has a good gait, appears to be well adjusted, and is normally active in high-school activities (Figs. 3-A through 3-D).

B. H., a boy, was born on May 3, 1950, with typical congenital cleft (lobster-claw) feet. Initially, the child was fitted with special shoes, but walking was difficult because in addition to the cleft-foot deformity there was marked internal tibial torsion which made him walk with severe toeing-in. Disarticulation at the left ankle was performed in May, and disarticulation at the right ankle in June of 1952. Multiple reconstructive procedures undoubtedly would have improved these feet, but because of experience with other juvenile amputees, it was decided that both the cosmetic and functional result would be best served by amputation. After surgery the patient was fitted with a Syme prosthesis bilaterally. The boy is now under active supervision in the out-patient clinic; he has developed normally, walks with a good gait, and is able to compete in a satisfactory manner with other children of his age except in the more strenuous types of physical activity. The family volunteered the information that they are well satisfied with his progress.

H. H., a boy, was born on September 2, 1943, with gross abnormalities of both feet, and was initially cared for in some other institution. Roentgenograms demonstrated synostosis of the distal one-quarter of each tibia and fibula with marked aplasia of the bones of the feet although there were more bones in the left than in the right foot. The initial treatment consisted in application of plaster-of-Paris casts to correct bilateral atypical talipes equinovarus. This treatment was unsuccessful and was discontinued for a period of one year, during which time the child had no treatment at all. When the boy was three years old, he was seen again, and corrective plaster-of-Paris casts were applied, but again these did not give satisfactory results. The patient was then fitted with an open lacer-cuff prosthesis to enable him to walk satisfactorily. On June 6, 1951, a left below-the-knee amputation was performed because the greater number of bones in the left foot made it impossible to make this foot comfortable in a lacer-cuff prosthesis. Although the child's function had been satisfactory in the prosthetic device the foot was sacrificed after careful consideration and at the request of the family, in order to make him more comfortable. The child has been followed continuously since surgery; he runs, jumps, and gets around in a seemingly normal manner, competing well with children his age. He is considered as having had a satisfactory result.

G. B., a boy, born on November 25, 1949, was cared for initially in some other institution. He was referred to this clinic when he was three and one-half years old. At that time the patient was found to have typical congenital cleft (lobster-claw) hands, with quite satisfactory function, and abnormalities of both legs. He had essentially no feet except rudimentary toes, and there was some angular deformity of both tibiae. At another hospital, disarticulation of the knee was carried out on the left in January and on the right in March of 1953. Initially, the patient was fitted with conventional prostheses but did not do well; subsequently, he was fitted with non-standard prostheses, using plastic buckets molded so as to give him a slight bow-legged appearance in order to bring his feet in under his body. The boy is currently under active supervision in the out-patient amputee clinic. Although the boy is walking satisfactorily, he is not so good a walker as many other patients because he is young and pays little or no attention to the development of grace or agility in gait. The patient is, however, capable of doing all the things that average children of his age are able to do, even though he is a bit more clumsy. The lobster-claw hands function satisfactorily, and to date nothing has been done for them (Figs. 4-A through 4-F).

### *Congenital Pseudarthrosis of the Tibia*

E. D., a girl, born on November 25, 1951, was first seen at the age of three months with an obvious congenital pseudarthrosis of the right tibia at the junction of the distal and middle thirds. Three attempts were made to correct the pseudarthrosis using intramedullary fixation with bone chips placed around the area of pseudarthrosis on two occasions and a bone graft from the father on another occasion. These all failed, and the intramedullary fixation was removed. The patient was fitted with an ischial weight-bearing brace with a lacer cuff in order

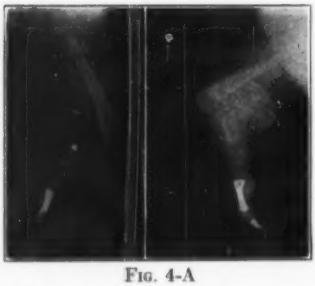


FIG. 4-A

FIG. 4-B

Fig. 4-A: G. B. Severe congenital abnormalities of both legs. There is marked hypoplasia and aplasia of all bone elements below the knees.
Fig. 4-B: Clinical appearance of the deformities.

FIG. 4-C

FIG. 4-D

Fig. 4-C: Roentgenogram made after amputations (knee disarticulations).
Fig. 4-D: After knee disarticulation. The patient shows end-bearing on the stumps. Note the congenital cleft (lobster-claw) hands.

to equalize the length of the legs and allow her to walk. She did not like the brace, and the family had great difficulty keeping her in it. After several consultations, a right below-the-knee amputation was performed on November 2, 1956. After amputation the patient was fitted with a standard below-the-knee prosthesis, and, at the time of writing, is comfortable and is walking very well. The family were initially reluctant to consider amputation, but are now extremely gratified with the functional and cosmetic result.

A. K., a woman, was born on September 25, 1927, with congenital pseudarthrosis of the left tibia but she was not seen for definitive care until she was eight years of age. At that time there was three inches of shortening of the left leg and a well established pseudarthrosis of the corresponding tibia with contractures of the posterior structures of the leg and a fixed equinus deformity of the foot and distal tibial fragment. Attempts to correct this angular deformity, first with plaster-of-Paris casts and then with leather cuffs and an ischial weight-bearing brace were continued for approximately nine months without success. Then, because of the great difference in the length of the legs, it was decided that amputation would be the treatment of choice, and on October 21, 1937, a left below-the-knee amputation was carried out. The patient was fitted with a standard below-the-knee prosthesis and since then has continued to be comfortable and has had satisfactory function.

D. W., a boy, was born on August 26, 1943, with congenital pseudarthrosis of the left tibia. The specific treatment the patient received prior to the time he was first seen here is

FIG. 4-E

FIG. 4-F

The patient is wearing non-standard above-the-knee prostheses (pylons); these have been more serviceable than the original standard prostheses. Articulation at the knees is planned at a later date.

not clearly established, but since an operative scar was present over the area of the pseudarthrosis, it is inferred that some operative procedure had been performed. In January 1947 a left below-the-knee amputation was carried out and the boy was fitted with a conventional below-the-knee prosthesis with which he learned to walk satisfactorily. After operation, a rapidly increasing scoliosis developed; this required the patient's being kept in bed for long periods of time until the scoliosis was corrected and spine fusion completed. Since that time this patient has not been seen, with the result that there is no detailed evaluation to indicate whether or not his present condition is as satisfactory as it was one year after amputation.

K. M., a girl, born on April 28, 1943, was cared for somewhere else initially; the information concerning this initial care is inadequate. Her earlier records indicated that a diagnosis of congenital pseudarthrosis of the tibia was made, and that multiple operative procedures of unknown types were carried out in the area of the pseudarthrosis. As the girl grew, the discrepancy in leg length increased, and it became impossible to fit her with a weight-bearing apparatus which was satisfactory with respect to both function and appearance. On September 5, 1955, a right below-the-knee amputation was done at some other hospital, and the patient was transferred to this hospital for prosthetic fitting and training. The girl was given a conventional below-the-knee prosthesis and has been under active supervision in the out-patient clinic since. She uses her limb well and has good function. In addition, the appearance of the limb has been greatly improved.

C. P., a young woman, was born on November 3, 1933, with congenital pseudarthrosis of the left tibia and was first seen within six months of birth. Treatment consisted in two autogenous-bone-grafting procedures, each of which failed; a series of double upright braces and shoe lifts to accommodate for the shortening of the affected extremity; and, for a time, a leather lacer cuff in order to give the area of fracture more stability. In April 1948, when the patient was fifteen years old, a left below-the-knee amputation was performed. Shortly thereafter she was fitted with a conventional below-the-knee prosthesis. This patient was followed from the time of amputation (April 1948) until March 1954, at which time she was married. She had good function, stability, grace and agility of gait, and an excellent time-distance factor. The patient was wearing a below-the-knee prosthesis that had two interchangeable feet—one set in enough equinus position to accommodate high-heeled shoes, and

FIG. 5-A

FIG. 5-B

Fig. 5-A: C. P. Anteroposterior and lateral roentgenograms of the congenital pseudarthrosis of the tibia.
Fig. 5-B: Anteroposterior and lateral roentgenograms of the amputation stump.

FIG. 5-C



FIG. 5-D

Figs. 5-C and 5-D: Photographs made seventeen years after amputation.
Fig. 5-C: The stump is a satisfactory below-the-knee length; there is good motion at the knee and no skin breakdown.
Fig. 5-D: The patient wearing a standard below-the-knee prosthesis. She prefers a pelvic band because it produces better stability.

FIG. 6-A

FIG. 6-B

FIG. 6-C

Fig. 6-A: B. C. Roentgenogram made after a left Gritti-Stokes amputation. There has been sacrifice of growth potential of the distal femoral epiphysis. I believe knee disarticulation would have been preferable.

Fig. 6-B: The above-the-knee stump is about mid-thigh in length.

Fig. 6-C: The patient wears a suction socket and tolerates it well.

the other set in neutral position so she could wear flat-heeled shoes for the working hours of the day. The appearance of the limb was good, and the patient was considered to have a satisfactory result (Figs. 5-A through 5-D).

### *Unknown Abnormalities*

B. C., a girl, born on December 17, 1940, was first seen when she was eight years old, one year after a left above-the-knee amputation had been performed for a congenital abnormality which, according to the patient, consisted of a small vestigial foot just below the knee. When the child was seven, a classic Gritti-Stokes amputation was performed. The patella was screwed to the distal end of the femur, resulting in complete destruction of the growth potential of the distal femoral epiphysis on the affected side. The patient was fitted with a suction-socket prosthesis and is currently at high school doing well as a student. Unfortunately, this patient has spina bifida and no proprioceptive sensation in her normal right extremity. As a result, she has had to use two crutches in order to maintain satisfactory balance and depends more on her crutches than she does on her artificial limb. Her limb has improved her appearance but has been of little functional value (Figs. 6-A, 6-B, and 6-C).

R. C., a boy, born on November 11, 1943, was first seen at the age of seven years with the history that on the day after birth amputation of a vestigial remnant was performed below the right knee. Two revisions for overgrowth of the tibial stump had been necessary—one in June 1951, and the other in May 1955. The patient was fitted with a standard below-the-knee prosthesis and is currently under observation. He is normally active for a patient of his age and his type of amputation. The appearance of the limb is satisfactory, and he is considered to have a good functional result (Figs. 7-A through 7-D).

J. M., a young man, was born on January 2, 1938. According to the patient's record (there are no preoperative roentgenograms available) he had congenital anomalies of both lower extremities which he described as consisting of very short tibiae with malformed feet. In July 1949 bilateral below-the-knee amputations were performed elsewhere and the patient was fitted with conventional below-the-knee prostheses. The patient has been followed since; he now walks well with satisfactory function and has no complaints.

M. W., a girl, born on May 1, 1951, was first seen at the age of sixteen months because of a deformity of the left leg, which by roentgenogram consisted of a very short tibia, a long fibula, and gross abnormalities of the tarsal bones. She was fitted first with a brace and then with a prosthetic brace in order to equalize the severe (three and one-half inches) discrepancy in leg length. In August 1956 the left foot was disarticulated at the ankle, and the fibula was resected. The fibula was then attached to the tibia in such a manner that the proximal tibial

FIG. 7-A

Fig. 7-A: R.C. Right amputation stump. This boy had revisions of the stump for overgrowth in both 1951 and 1955. Amputation had been performed in 1943, one day after birth.

epiphysis was retained and the distal fibular epiphysis was put at the distal end of the stump. The patient was then fitted with a conventional below-the-knee prosthesis, and during the short period of follow-up has been getting along well and walks satisfactorily.

### *Congenital Absence of the Tibia*

H. Z., a boy, was born on February 2, 1953, with congenital abnormalities of both legs characterized by absence of the tibiae and hypoplastic feet, which consisted of soft tissue primarily and were attached just at the level of the knee. In March and April of 1956, when the boy was three years old, bilateral knee disarticulations were done at some other clinic. Since that time further examination of the child disclosed a short femur and a dislocated hip with a false acetabulum on the right side and a congenital cleft (lobster-claw) hand on the right. The patient was fitted with bilateral above-the-knee prostheses and is now under active out-patient care. His standing balance is good as is his time-distance factor, but he is clumsy in his walking, with marked abduction of the left leg. It is believed that he will progress to a more satisfactory result.

S. K., a girl, born on October 25, 1941, was originally cared for at some other orthopaedic clinic because of nearly complete absence of both legs below the knees except for hypoplastic feet attached at the level of the knees. Bilateral knee disarticulations with retention of the distal femoral epiphyses were performed in April 1946, when the patient was five years old. She was then seen in our out-patient amputee clinic where she was fitted with bilateral above-the-knee prostheses with suction sockets. She has been under active supervision in the out-patient clinic from that time to the present and has been wearing the suction sockets during the entire time. She now has good stability, a quite satisfactory gait, and a time-distance factor which is satisfactory for a bilateral above-the-knee amputee. By virtue of lengthening her artificial limbs from time to time it has been possible to maintain her height and it is essentially the same as that of other children of her age. She has a satisfactory result.

B. H., a woman, born on May 6, 1933, had nearly complete absence of the right leg from the knee down with a hypoplastic foot attached at about the level of the knee with some

FIG. 7-B

FIG. 7-C

FIG. 7-D

Fig. 7-B: Lateral view of the amputation stump.
Fig. 7-C: Anteroposterior view of the stump.
Fig. 7-D: Photograph of the patient wearing his prosthesis.

bone structure between the knee and the foot. A right below-the-knee amputation had been performed at some other hospital in 1938. The patient wore a below-the-knee prosthesis until she was seen here in 1951. At that time it was observed that she did not utilize what knee motion she had and walked like an above-the-knee amputee. Careful review of the situation indicated that her stump was so short and had such minimal function that it was of no value. Accordingly, in 1952 an above-the-knee amputation was performed on the right side, and she was fitted with a suction-socket prosthesis with which she learned to walk satisfactorily. The patient was followed until May 1954, when she was over twenty-one years of age; she was working and had no complaints referable to her amputation. Follow-up by letter since that time indicated that she is continuing to do well.

### *Congenital Abnormality of the Proximal Portion of the Femur*

D. W., a young woman, born on January 16, 1940, was treated elsewhere from February 1941 to December 1950. She was born with almost complete absence of the left leg below the knee with the four-toed left foot at the same level as the opposite knee and a true congenital coxa vara of the left hip. Apparently, the patient was treated in plaster-of-Paris casts and ischial weight-bearing braces until November 1952. In June 1947 her left leg was nine and one-half inches shorter than her right, and in August 1949 there was a difference of ten and one-half inches in leg length. In November 1952 a left above-the-knee amputation was performed, and the patient was fitted with a suction-socket prosthesis. She has been under observation at our clinic since being fitted with the prosthesis and at this time is a well adjusted girl nearly seventeen years of age who is able to get around satisfactorily.

T. O., a boy, born on April 10, 1945, was first seen at the age of four months, when he was found to have a short right leg. Roentgenograms showed a congenital abnormality of the proximal end of the femur, shortening and anteromedial bowing of the tibia, and complete absence of the fibula on the affected side. The patient used an ischial weight-bearing brace until May 1950, when a disarticulation of the foot was accomplished, and the patient was fitted with a suction-socket prosthesis. He has continued to wear this and at this time is a normally active twelve-year-old boy (Figs. 8-A through 8-E).

J. R., a young man, born on June 23, 1934, was first seen when he was three years old. At that time he had bilateral congenital anomalies of the lower extremities. On the left there was a valgus deformity of the foot and absence of some of the toes, and on the right there

FIG. 8-A

FIG. 8-B

Fig. 8-A: T. O. Roentgenogram showing severe deformity of the proximal portion of the femur. There are remnants of the neck and the trochanter; these may represent pseudarthroses secondary to congenital coxa vara.

Fig. 8-B: This photograph shows the severe inequality of leg length and talipes equinovalgus. Roentgenograms of the leg showed absence of the fibula and an anterior angular deformity of the distal half of the tibia.

FIG. 8-C

FIG. 8-D

FIG. 8-E

Figs. 8-C and 8-D: The length of the residual stump after disarticulation at the ankle; fully extended, it is equal to the normal contralateral thigh. The level of the knee joint is indicated.

Fig. 8-E: The patient wearing a non-standard suction-socket limb. The prosthesis is non-standard in that it has an anterior convexity to accommodate the flexion deformity of the hip. The webbed pelvic band is worn for added security.

was an abnormal knee joint with good quadriceps power and a valgus deformity of the foot which had three webbed toes. This patient was treated with various types of braces and shoe lifts until August 1944 when, at the age of ten, disarticulation of the left foot was performed. The patient was fitted with a prosthesis with which he made quite satisfactory progress. Three years later, in August 1947, a below-the-knee amputation was done on the left side and the

stump was fitted with a non-standard suction socket. The patient was followed until February 1950, at which time his condition was satisfactory and he was doing well in school. The patient now reports by letter that he is employed and is getting along satisfactorily. It is interesting that this boy had severe failure of completion of rotation of the lower limb bud on the affected side, with the result that the entire leg on the left side was held in the fetal position of flexion, abduction, and external rotation.

## DISCUSSION

In this series of thirty-one patients, severe congenital abnormalities of the lower extremities were treated by amputation. The anomalies so treated were: congenital kyphosis of the tibia, congenital abnormalities of the feet, congenital pseudarthrosis of the tibia, congenital absence of the tibia, congenital abnormalities of the proximal part of the femur, and a few abnormalities of unknown type which were treated by amputation before coming under our care. The types of amputation performed and the prostheses prescribed for the patients just mentioned have been indicated in the case reports. No attempt has been made to develop a rating scale because of the complexity and multiplicity of factors that influence the result of an amputation. From the viewpoint of prothetic fitting, however, there were no failures because none of the patients in this series could not or would not wear the limbs. All of the patients in this series for the extent of their follow-up were good limb wearers and performed well although there were wide variations in the excellence of performance. These variations were related primarily to age and type of amputation. Young amputees walk with the same graceless, immature walking habits as normal children of the same age. If properly supervised and schooled at intervals in the use of their prostheses so that poor walking habits do not become integrated, these children's gait patterns can be expected to improve at a rate which is roughly parallel to the improvement in gait achieved by a normally maturing child of the same age.

All bilateral lower-extremity amputees walk less well than unilateral ones. This is true of children as well as adults. In general, juvenile amputees make a better adjustment to their handicap than do adults. Certainly, those who grow up with their artificial limbs develop a proficiency in function that surpasses that of the average adult.

The below-the-knee amputees perform better than those with above-the-knee amputations, because there is a longer lever arm, and voluntary control of knee function is retained. This permits physiological variable cadence and promotes better gait patterns.

Ankle disarticulations, in general, give better results than either above-the-knee or below-the-knee amputations for an ankle disarticulation gives an element of end-bearing which increases the sensory feedback from the amputated limb. This produces a greater sense of security and stability and leads to better performance.

Four of the ten patients with congenital kyphosis of the tibia (six amputations) were treated by ankle disarticulation. Of these four patients the bilateral amputees have been followed for nine and four years, respectively, whereas the two unilateral amputees have been followed for four years and six months, respectively. Revision has not been required to date. Better prosthetic fabrication has permitted comfortable fitting despite the angular deformity of the tibia.

For the amputee under twelve years of age, there is little if any social compulsion to walk well. The limb is a means to an end. The end is to attain enough speed and stability to compete with others of the same age. At this age there is little or no concern with social or physical graces. These patients measure their performance against their contemporaries.

Bipedal ambulation and prosthetic acceptance were accomplished in all instances but performance was influenced by the age of the patient, the level of amputation, the presence of associated abnormalities, and whether the condition was unilateral or bilateral. Taking these factors into consideration the performance of each patient was considered satisfactory.

Scars, neuromata, short stumps, spurs, and skin breakdown are not the complicating factors in children that they are in adults. Frantz and I [1], in surveying one hundred and ninety-two juvenile amputees, reported this, and the results in the patients in this series confirm our conclusion.

The syndrome of a painful phantom limb was not encountered in this series, and never is in child amputees. Why this is true is not clearly determined, but it is well established that this misfortune—a complication of amputation in adults—is not a problem in children.

In all thirty-one patients there were only three revisions for overgrowth of the tibia, and two of these were in the same patient. It is believed that this incidence of reoperation either for reamputation or correction of overgrowth is not sufficiently great to be a deterrent to amputation as a method of treatment for these anomalies.

There were no part-time wearers of prostheses in this series. The only time that any patient was without his artificial limb was when it was mechanically so defective that he could not use it.

The response of the patient was good, but this was not a valid method of evaluating results. All of the more mature patients who requested amputation were completely satisfied. Those who had their amputations early were unable to compare their state after amputation objectively with that before operation.

Parental acceptance was excellent. Since all of the patients in this series were still children at the time of amputation, parental consent had to be obtained. In no instance was any child in this group withdrawn from care because of dissatisfaction with the result. Many of the parents volunteered to talk to other parents concerning the advantages of amputation as a reconstructive technique.

The indications for amputation as a method of treatment for severe congenital anomalies of the lower extremities are difficult to define exactly. They fall into two major categories, which include (1) functional defects of either anatomical or mechanical origin, and (2) disfigurement. The anatomical functional defects which constitute indications for amputation are: severe inequality of leg length, malrotation of the limbs, unstable foot or feet in positions unsuitable for weight-bearing, and unstable proximal joints. A mechanical defect which constitutes an indication for amputation is the functional impairment arising from the weight, clumsiness, and discomfort of the apparatus, such as special shoes, shoe lifts, braces, and leather cuffs, used to compensate for the anatomical deficiencies.

The indications which fall into the category of disfigurement include the unsightly anatomical defect itself and the appearance of the mechanical appliance used for its correction. Here amputation may be indicated to eliminate a severely deformed portion of the extremity and to permit the use of a prosthesis which will conceal the defect instead of accentuating it, as is the case with some types of mechanical apparatus that must be used if amputation is not done.

## CONCLUSIONS

Amputation has a place as a reconstructive operative procedure in selected cases of certain congenital abnormalities of the lower extremity.

Amputation is indicated where the deformed extremity is so short that leg-length equalization would produce a greater deformity.

When the life history of a deformity is clearly known and the prognosis is definite, primary amputation may be advantageous.

This series contains no failures as a result of treatment by amputation.

Ankle disarticulation in congenital kyphosis of the tibia (congenital absence of the fibula) may be preferable to below-the-knee amputation above the angular deformity of the tibia.

NOTE: The patients reported here were all seen and cared for at the Area Amputee Center of Grand Rapids, Michigan. This service is sponsored by the Michigan Crippled Children's Commission and further aided by a grant from the Children's Bureau. The Center is located at the

Mary Free Bed Children's Hospital and Orthopaedic Center. The cooperation of these services, of the personnel of each unit, and of my professional colleagues has been given generously. Completion of the work has been materially aided by this generosity.

REFERENCES

1. Aitken, G. T., and Frantz, C. H.: The Juvenile Amputee. J. Bone and Joint Surg., **35-A**: 659-664, July 1953.
2. Babb, F. S.; Ghormley, R. K.; and Chatterton, C. C.: Congenital Coxa Vara. J. Bone and Joint Surg., **31-A**: 115-131, Jan. 1949.
3. Badgley, C. B.; O'Connor, S. J.; and Kudner, D. F.: Congenital Kyphoscoliotic Tibia. J. Bone and Joint Surg., **34-A**: 349-371, Apr. 1952.
4. Coventry, M. B., and Johnson, E. W.: Congenital Absence of the Fibula. J. Bone and Joint Surg., **34-A**: 941-956, Oct. 1952.
5. Harmon, P. H., and Fahey, J. J.: The Syndrome of Congenital Absence of the Fibula. Report of Three Cases with Special Reference to Pathogenesis and Treatment. Surg., Gynec., and Obstet., **64**: 876-887, 1937.
6. Kite, J. H.: Congenital Deformities of Lower Extremities. *In* Surgical Treatment of the Motor-Skeletal System. Edited by F. W. Bancroft and H. C. Marble. Ed. 2, Part 1, pp. 23-104. Philadelphia, J. B. Lippincott Co., 1951.
7. Thompson, T. C.; Straub, L. R.; and Arnold, W. D.: Congenital Absence of the Fibula. J. Bone and Joint Surg., **39-A**: 1229-1237, Dec. 1957.

# Stress Fractures of the Calcaneus

BY J. W. LEABHART *Medical Corps, United States Naval Reserve*
*From the United States Naval Hospital, Beaufort, South Carolina*

A stress, march, fatigue, or insufficiency fracture can be defined as a break in the continuity of presumably normal bone caused by rhythmically recurring subthreshold traumata.

Probably, the first stress fractures were reported by Breithaupt in 1855 when he described the painful foot of soldiers. With the advent of the roentgenogram at the turn of the century, this pain in the foot was found to be due to a fracture of the metatarsal [11]. For the next forty years many and varied theories were set forth to explain the etiology of this fracture that occurred without apparent direct trauma [2,3,8,9,13]. Most of the reports were based on series that were small, and the theories proposed as to the causation of the fractures were concerned with either mechanical factors, such as spastic, flat fore part of the foot, short first metatarsal, or inflammatory reactions which were thought to lead to fatigue, osteoporosis, and fracture. Scheller reported 590 cases of stress fractures, 488 of which were in the metatarsal. This series included four cases of stress fractures of the calcaneus. In 1942 and 1943 Hartley [4,5] set forth the theory of bone exhaustion that was analogous to the fatigue of common metals, basing his opinion on the spectroradiographic studies of Henschen, Straumann, and Bucher. This is the theory held by most observers today.

During World War II many cases of stress fracture were reported as occurring in nearly every bone in the body: ulna; humerus; pelvis; upper and lower parts of the femur; upper, middle, and lower parts of the tibia; upper and lower parts of the fibula; calcaneus; tarsal cuneiform; and metatarsal.

Hullinger, in one of these papers, described fifty-three cases of stress fractures of the calcaneus in army recruits in Georgia. In 1946 Van Demark and McCarthy reported stress fractures of the calcaneus to be a frequent cause of painful heels in soldiers but did not enlarge on the subject.

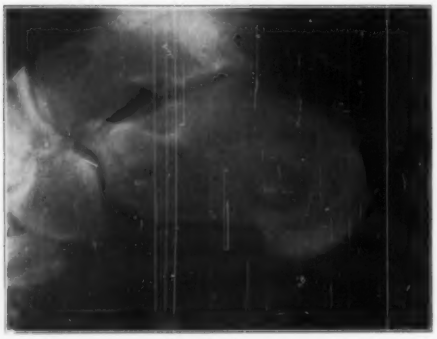


FIG. 1-A

FIG. 1-B

Fig. 1-A: Roentgenogram of a twenty-year-old recruit made two weeks after onset of typical symptoms of stress fracture of the calcaneus, showing no fracture.

Fig. 1-B: Four weeks after onset of the symptoms a fracture line shows in the postero-superior calcaneus.

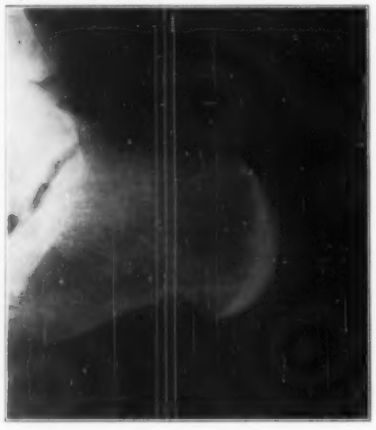


FIG. 1-C

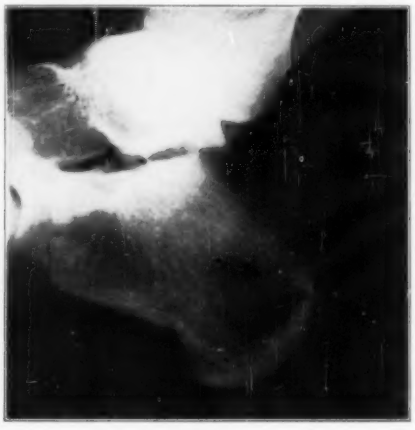


FIG. 1-D

Fig. 1-C: Fifteen weeks after the onset of the symptoms, partial resolution of the fracture line is shown.

Fig. 1-D: Thirty weeks after the onset of symptoms the fracture line is barely discernible.

## CLINICAL MATERIAL

In the present study, 134 patients with stress fractures of the calcaneus were diagnosed in United States Marine Corps recruits at Parris Island, South Carolina, from January 1957 to August 1958. The incidence of these fractures was 0.45 per cent of the total number of new recruits. All patients were admitted to the United States Naval Hospital, Beaufort, South Carolina, and were examined and treated by myself. In this study, ninety-eight patients had bilateral fractures. Seventeen fractures were diagnosed of the right heel only, and nineteen of the left heel. Only thirteen of these 134 patients had a history of having been physically active or having participated in athletic endeavor in the three years prior to enlistment. Two of these thirteen patients were farmers, and one was a logger. Fifty-eight of the 134 patients were over twenty years of age, the oldest being twenty-six. The average age was twenty years. One patient was a Negro and three were women Marine recruits. The percentage of abnormal foot structure, such as marked pronation, clawing of toes, or mild cavus deformities, was not significant.

At one time during this study, 450 recruits in their fourth week of routine training were examined and questioned. Each recruit completed a questionnaire

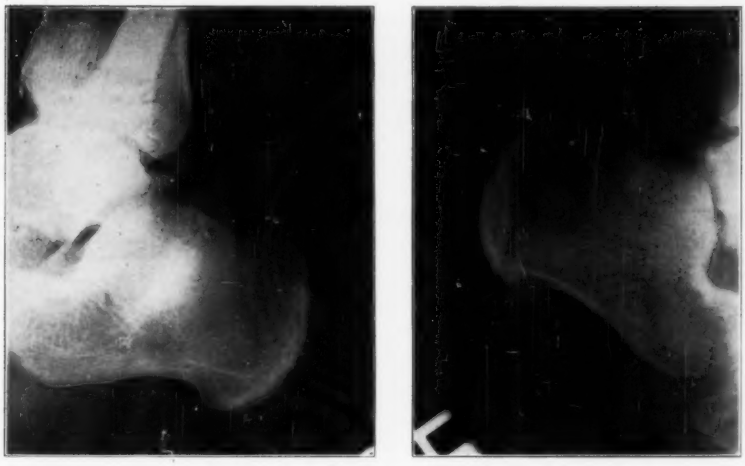


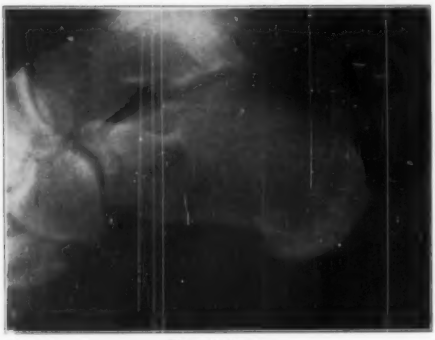
FIG. 2

Roentgenograms of the calcanei of a twenty-two-year-old recruit made eight weeks after the onset of the symptoms, showing a cortical fissure and periosteal reaction on the right side with a small fracture on the left side.

FIG. 3

Roentgenogram of the calcanei of a twenty-two-year-old recruit made eight weeks after the onset of bilateral symptoms, showing symmetrical fractures. The right leg had just been removed from plaster immobilization of six weeks for traumatic fracture of the lower part of the fibula. Note the extent of the fracture with the superimposed disuse osteoporosis.

concerning activities prior to enlistment, including occupation, footwear, maximum and minimum body weights, athletic endeavor, and attitude toward the Marine Corps. A brief statement of old or new, or both, foot ailments was requested. Roentgenograms of the heels were made after examination of the lower extremities. Slightly over 50 per cent of this group were athletically active prior to enlistment. The age distribution was similar to that for the entire recruit depot at that time (average age, 18.05 years). From this group, two recruits had already been admitted to the hospital for treatment of stress fracture of the calcaneus. Four new cases were diagnosed. All four patients had a history and physical examination



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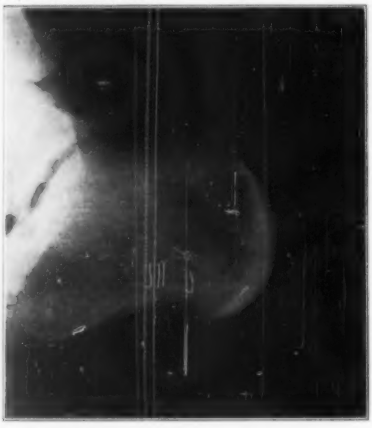
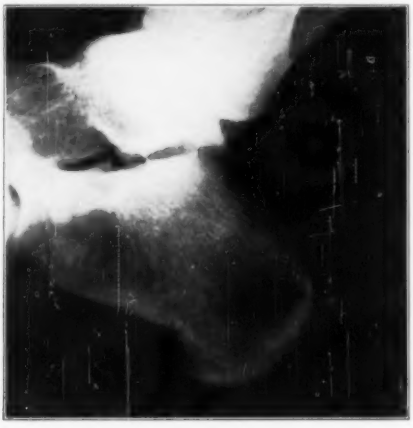


FIG. 1-C



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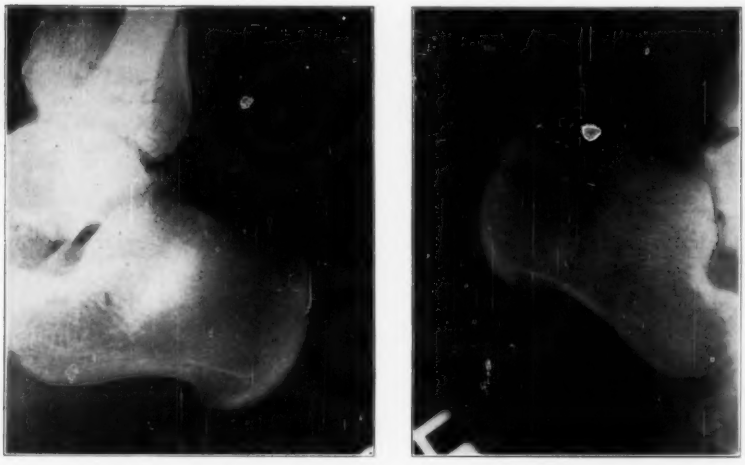

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compatible with stress fractures of the calcaneus, but they were able to tolerate the discomfort. These four recruits completed training without treatment.

Comparison of the age and physical activity of the patients with calcaneal fractures with the age and physical activity of all recruits revealed that the patients with fractures were older and were less active prior to enlistment. The height and body weight of the recruits with fractures did not differ from that of the 450 recruits who were examined.

## CLINICAL SIGNS AND SYMPTOMS

All patients complained of a painful swelling of the heel (or heels) which occurred in the first ten days of training. No history of specific trauma could be elicited, but most patients felt that "digging in" was responsible. Digging in refers to a method of maintaining cadence while marching in which one or the other heel is slammed down on the macadam of the drill fields. During the first two weeks of training the recruit must walk "double time" everywhere and is on his feet for eight to ten hours a day. No heavy packs are worn at this early time of training.

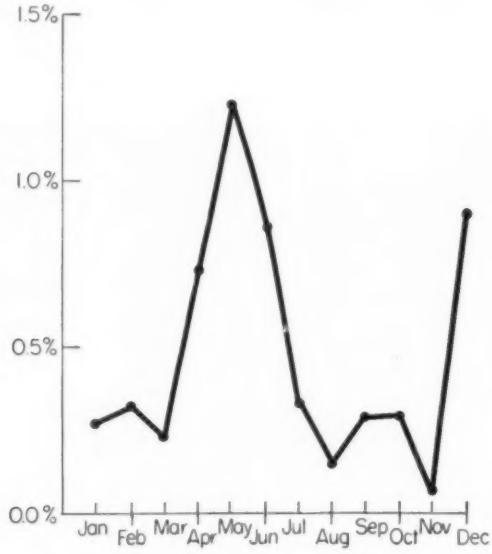


CHART I

Two signs could always be elicited when these patients were admitted to the hospital. The first was edema in the area of the precalcaneal bursa, anterior (or deep) to the Achilles tendon. Five cubic centimeters of clear straw-colored fluid was aspirated from this area in one patient. The edema sometimes extended from the bursal area anteriorly to the malleoli, sometimes masking the bone contours of the ankle. Fluctuance in the precalcaneal area was noted in a considerable number of patients. Whether this edema was due to fluid in the precalcaneal bursa or to reaction around the fracture site itself could not be determined. The second sign was tenderness over the posterosuperior calcaneus, presumably at the fracture site itself. There was no evidence of hemorrhage or inflammation. Stretching of the heel cord by dorsiflexion of the foot did not increase the pain. The edema sometimes subsided overnight, but the tenderness persisted for two to four weeks.

Roentgenograms were negative at the time of the first examination, which was normally three to five days after the onset of the symptoms. Ten days after the onset of symptoms a definite line or density could usually be seen in the pos-

terosuperior portion of the calcaneus perpendicular to the trabecular stress lines (Figs. 1-A and 1-B). The fracture first appeared on the roentgenogram as an increase in density with or without periosteal reaction which was located near the superior margin anywhere from the articular surface of the calcaneotalar joint to the tuberosity of the calcaneus. The earliest time at which a fracture was visualized in this series was seven days after the onset of symptoms; the latest time was at thirty days. For two or three weeks the density increased in length inferiorly and then remained relatively constant for six weeks (Figs. 1-C, 2, and 3). The osteosclerosis then gradually faded, and the normal trabecular pattern reappeared. One patient was observed at thirty weeks after the onset of symptoms, at which time the fracture line was barely discernible (Fig. 1-D).

## TREATMENT

Treatment of the patients in this series consisted in bed rest for one week, at which time roentgenograms were made which usually revealed the fracture. Regardless of roentgenographic findings, however, four-point weight bearing with crutches was instituted with one-half-inch, sponge-rubber heel inserts in both shoes. Crutches were discontinued when symptoms permitted, usually in four to six days, at which time those patients with negative roentgenograms were returned to duty if symptoms did not recur with weight-bearing. Not infrequently, these patients had to be readmitted some days later with typical stress fractures. All patients usually returned to duty in eight weeks. As a general rule, attempts to discharge patients earlier than eight weeks were unsuccessful owing to a high rate of recurrence of symptoms. Even at eight weeks some swelling and pain recurred which most patients claimed to be insignificant compared with the original symptoms. No displacement of any of these fractures was noted.

## DISCUSSION

Review of the records of all patients admitted in the two years prior to this study with diagnoses of lesions about the ankle and heel revealed twenty-two patients with histories compatible with and roentgenograms positive for stress fracture of the calcaneus. Thirty-four other patients had compatible histories but no roentgenographic proof of fracture. The diagnoses in these instances included tenosynovitis, tendinitis, arthritis, rheumatic fever, cellulitis with lymphangitis, and neurosis. Several patients had been given inaptitude or medical discharges.

The over-all incidence of these fractures was 0.45 per cent. The incidence of these fractures by month was determined for the period of January 1 to December 31, 1957, as illustrated in Chart I. From this it is apparent that the incidence is high in the spring, reaching a maximum of 1.23 per cent in May, and that there is another increase in incidence in December, reaching 0.9 per cent. The reason for this seasonal variation was not determined. It was postulated that the summer and fall recruits were recent graduates from high school and consequently in better physical condition than those starting their training in the winter and spring.

In an attempt to decrease the incidence of these fractures, five platoons (approximately 375 recruits) were trained in dress shoes and prohibited from digging in for the first three weeks of their training. Sponge or felt heel inserts were provided for all recruits who had pain or swelling, or both, of the heels. Four recruits from these selected platoons were admitted with stress fractures of the calcaneus, an incidence of 0.94 per cent, which is well above the 0.45 per cent average for the total study period.

During the period that this study was in progress the diagnosis of stress fracture of bones other than the calcaneus was made 203 times in patients admitted to the hospital. These fractures were located in the upper and lower parts of the fibula, upper and lower parts of the tibia, metatarsals, obturator ring, and femoral neck. Three tibial fractures, four fibular, and four metatarsal fractures occurred

in patients who previously had sustained calcaneal fractures. This number refers only to the number of times that these fractures were diagnosed. It should not be taken as indicating the relative incidence of these fractures, since many patients with metatarsal and fibular fractures are not admitted to the hospital. It is estimated from out-patient records that calcaneal fractures represent 19 per cent of all stress fractures seen by medical personnel.

## CONCLUSIONS

Stress fractures of the calcaneus are a frequently unrecognized source of heel pain in Marine recruits which may be diagnosed as a more serious condition, such as rheumatic fever, arthritis, and neurosis. Occasionally, these erroneous diagnoses lead to medical discharges. There is a definite relationship between poor physical condition and stress fractures. Many recruits are able to complete training with these fractures without loss of time. There is no known simple method of decreasing their incidence—such as the use of shoe corrections, heel lifts, or sponge-rubber pads—once recruit training has begun. A short graduated training period prior to routine recruit training is needed.

## SUMMARY

One hundred and thirty-four cases of stress fracture of the calcaneus in Marine Corps recruits are presented with a brief review of the literature. Advancing age and lack of physical activity prior to enlistment appear to increase the incidence of these fractures. A method of treatment is outlined, consisting in restricted activity. The only complication of these fractures is the erroneous diagnosis of a more serious condition.

## REFERENCES

1. Breithaupt [H. S.]: Zur Pathologie des menschlichen Fusses. Medicin. Zeitung, **24:** 169-171, 175-177, 1855.
2. Deutschländer, Carl: Über entzündliche Mittlefussgeschwülste. Arch. f. Klin. Chir., **118:** 530-549, 1921.
3. Dodd, Harold: Pied Forcé or March Foot. British J. Surg., **21:** 131-144, 1933.
4. Hartley, J. B.: Fatigue Fracture of the Tibia. British J. Surg., **30:** 9-14, 1942.
5. Hartley, J. B.: "Stress" or "Fatigue" Fractures of Bone. British J. Radiol., **16:** 255-262, 1943.
6. Henschen, C.; Straumann, R.; and Bucher, R.: Ergebnisse röntgenspektrographischer Untersuchungen am Knochen. Krystallitbau des anorganischen und des organischen Knochens. Deutsche Zeitschr. f. Chir., **236:** 485-514, 1932.
7. Hullinger, C. W.: Insufficiency Fracture of the Calcaneus Similar to March Fracture of the Metatarsal. J. Bone and Joint Surg., **26:** 751-757, Oct. 1944.
8. Jansen, Murk: March Foot. J. Bone and Joint Surg., **8:** 262-272, Apr. 1926.
9. Momburg: Die Entstehungsursache der Fussgeschwulst. Deutsche Zeitschr. f. Chir., **73:** 425-437, 1904.
10. Scheller, F.: Überlastungsschäden am Knochengerüst junger Männer. Med. Welt, **13:** 1333-1336, 1939.
11. Stechow: Fussödem und Röntgenstrahlen. Deutsche Milit. Zeitschr., **26:** 465-471, 1897.
12. Van Demark, R. E., and McCarthy, P. V.: March Fracture. Radiology, **46:** 496-501, 1946.
13. Weaver, J. B., and Francisco, C. B.: Pseudofractures. A Manifestation of Non-Suppurative Osteomyelitis. J. Bone and Joint Surg., **22:** 610-615, July 1940.

# Paraplegia in Children

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The newer knowledge about paraplegia which has accrued in the past fifteen years has been derived largely from experience with adult patients; relatively few reports concern children.

In 1953, Jaeger reviewed the case histories of sixty-eight infants born with myelomeningoceles. He reported that among those with total bladder paralysis he " could not locate a single patient that had survived the first ten years of life".

Bluestone and Deaver, in 1956, reported their experience with forty-five children of various ages up to seventeen years and with varying degrees of motor and sensory paralysis due to spina bifida with myelomeningocele. These authors believed that such children can become "useful, independent and self-supporting members of the community".

TABLE I
EXTENT OF NEURAL-ARCH DEFECTS

| Upper Limit of Defect | | No. of Patients * |
|---|---|---|
| T6, T8, T10 | 1 at each level | 3 |
| T11 | | 5 |
| T12 | | 1 |
| L1 | | 3 |
| L2 | | 7 |
| L3 | | 10 |
| L4 | | 9 |
| L5 | | 5 |
| S1 | | 1 |
| | | 44 |

* Entire sacrum bifid in all patients.

Resolution of the apparent conflict between Jaeger's report and the conclusion of Bluestone and Deaver is found in the age groups they considered. Mortality is high in the early years of life, as Jaeger found. There is, nevertheless, a small percentage of survivors, and in this group, according to our experience, life expectancy is surprisingly good if urological care is adequate. The prognosis expressed by Bluestone and Deaver therefore appears to be correct.

This review considers both congenital and acquired paraplegia in children. It is limited to two major topics: (1) prognosis for life and for self-sufficiency and (2) requirements for orthopaedic care.

In both groups of paraplegia, congenital and acquired, a clear idea as to prognosis for life and for ultimate self-sufficiency should form the roots of long-term management of these paraplegic children. The second topic, the requirements for orthopaedic care of such children, is elaborated here because in this respect, among others, the children differ strikingly from paraplegic adults.

It cannot be emphasized too strongly that the presence of extensive paralysis during the growing years of childhood is a potent cause of skeletal deformities. This concept is well recognized in the literature dealing with poliomyelitis, much of which has been derived from experience with children. On this account, at present, the literature on childhood poliomyelitis is in some ways a better guide to the orthopaedic management of paraplegic children than most of the literature on paraplegia itself.

An analysis of the surgical procedures already done will be presented, together with comments on the conditions for which these procedures were done. Although each condition that commonly requires surgery must be presented singly, it should be noted that the paraplegic child seldom presents a single orthopaedic problem. On the contrary, deformities often are multiple, and a series of corrective procedures may be required to get the lower extremities into good alignment for weight-bearing. All the factors that contribute to an integrated judgment as to what surgery is necessary and sufficient in any given case and what the sequence of procedures should be cannot be discussed here. It is possible only to point out that the presenting deformities should be considered in their totality before any corrective surgery is begun, and the sequence of operative work should be carefully planned at the outset.

This presentation reviews sixty-five children with gross lesions of the spinal cord, of which forty-eight were congenital and seventeen were acquired. All these children are, or have been, patients at the Massachusetts Hospital School during the ten years ending on March 1, 1958.

TABLE II
EXTENT OF NEURAL-ARCH DEFECTS NOT INCLUDING ENTIRE SACRUM *

| Level | No. of Patients |
|---|---|
| No sacral defect | |
| L1—L4 | 1 |
| L3—L6 | 1 |
| Partial sacral defect | |
| L3—S1 | 1 |
| L4—S2 | 1 |
| | 4 |

* See Figure 5.

CONGENITAL PARAPLEGIA

The ages at admission in the group with congenital paraplegia were as follows: there were ten patients from one to five years of age; there were twenty-eight patients from five to ten years of age; and there were ten patients over ten years of age. The average length of stay at the Hospital School was six years.

In the group with congenital paraplegia all forty-eight patients had a diagnosis of spina bifida. Of these, thirty-two had operative repair of their myelomeningoceles before admission, and five had repair after admission to the Hospital School; nine have lesions that remain unoperated; and two have no presenting masses.

In forty-four of the forty-eight patients the wide neural-arch defect included all of the sacral segments and reached upward to various lumbar and thoracic levels (Figs. 1, 2, 3, and 4). The distribution of the wide vertebral defects, indicating the extent of corresponding spinal-cord malformations, is summarized in Table I.

The remaining four patients have wide neural-arch defects entirely above the third sacral segment; the distribution of these lesions is shown in Table II.

Detailed correlation of the neuromuscular and sensory deficits with the site and extent of the various skeletal defects is not presented here. It will suffice to state that the segmental level of motor paralysis in the spinal cord corresponded approximately with the skeletal segments involved in the spina bifida. Tables I and II make it clear that the great majority of these patients have complete or nearly complete paralysis of the lower extremities, and that many have extensive paralysis of the lower trunk as well. Paralysis of the bladder was present in forty-six of the forty-eight patients. The two patients who achieved successful bladder control required several years of training.

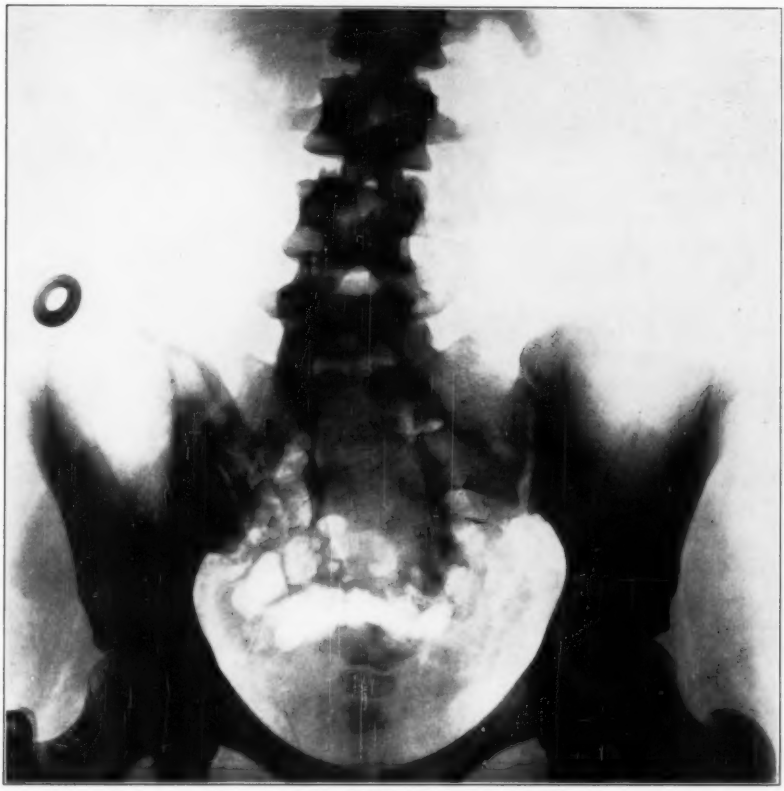

FIG. 1
Sacrum Bifidum

*Prognosis*

*Life Expectancy*

The data in Table III show the present ages of the forty-one patients with congenital paraplegia who are still living and the ages at death of the seven who died. The average age of those still living is fifteen and one-half years; six are from twenty to thirty years old.

These figures do not give a true picture of the life expectancy in congenital paraplegia because (1) they do not include children in the earliest years of life, when the mortality is highest, and (2) the total life span still remains to be determined in forty-one of the forty-eight patients. However, these figures do indicate that children with congenital paraplegia who survive the early years of life have a far better chance for reaching adult life than is generally believed. Consequently, if allowance is made for obvious exceptions, such as patients with impaired mentality or an extreme physical handicap, plans for the treatment and training of these children from the earliest years should be governed not by the expectation of a short life but by the expectation of a life long enough to require a gainful occupation.

*Ambulation*

Next in prognostic importance, and second only to life expectancy, is the patient's prospect of walking independently. This is the key to many aspects of self-sufficiency—physical, economic, emotional, and social. The types of gait achieved

TABLE III
AGES OF PATIENTS

| Ages of Living Patients (as of March 1, 1958) | | Age at Death of Deceased Patients | |
|---|---|---|---|
| Age | No. of Patients | Age | No. of Patients |
| 7 to 9 | 5 | 11 | 1 |
| 10 to 12 | 13 | 12 | 3 |
| 13 to 16 | 8 | 13 | 1 |
| 17 to 19 | 9 | 25 | 1 |
| 21 to 24 | 3 | 26 | 1 |
| 25 to 30 | 3 | | |
| Totals | 41 | | 7 |

TABLE IV
FUNCTIONAL EVALUATION OF GAIT

| | | Type of Gait | | | |
|---|---|---|---|---|---|
| | No. of Patients | Swing-through and Pull-to | Pull-to Only | 4 Point or 2 Point | Good in All Types of Gait |
| *Balance and Endurance* | | | | | |
| No serious gait problems | 3 | | | | |
| Not ambulatory | 9 | | | | |
| In training, endurance not rated | 4 | | | | |
| Ambulatory with excellent balance | | | | | |
| Endurance poor or fair | 6 | 1 | 2 | 3 | |
| Endurance good or excellent | 26 | 6 | 2 | 3 | 15 |
| | 48 | | | | |

TABLE V
SURGICAL PROCEDURES ON THE HIP

| Stabilizing Operations | No. | Mobilizing Operations | No. |
|---|---|---|---|
| Shelf operations | 7 | Release of flexion contractures | 20 |
| Rotational osteotomy | 1 | Release of adduction contractures | 2 |
| Closed reduction | 2 | Erector spinae transplant | 3* |
| Open reduction | 4 | | |
| Totals | 14 | | 25 |

* Three erector spinae transplants were done in 1951 and 1952 to relieve hip flexion contractures and also in the belief that posterior stability to prevent jackknifing would improve standing balance. We found, however, with added experience that anterior flexion release followed by immediate ambulation and by restricted sitting have been just as effective and require less surgery.

by the forty-eight children with congenital paraplegia are summarized in Table IV.

*Poor* and *fair* ratings indicate endurance sufficient to allow the patient to walk under supervision only. *Good* and *excellent* ratings refer to endurance in walking which is adequate to meet the patient's own needs for independent ambulation. More specifically, a rating of *good* signifies crutch-walking habitually, but with limitations imposed by fatigue or the need to use a wheel chair for relatively long distances. To qualify as having *excellent* endurance a patient must be on a program of full activity without using a wheel chair at all. The maximum

FIG. 2

Neural-arch defect from the fifth lumbar vertebra through the sacrum. Note the bilaterally dislocated hips.

distance which a patient with excellent endurance is expected to travel at one time is about one-quarter of a mile (Fig. 6).

As a general rule, a child with total paraplegia should be regarded as capable of developing efficient ambulation using crutches and braces. Among the nine patients listed in Table IV as not ambulatory, only four are regarded as unlikely ever to learn to walk because of poor physical condition or gross deformity, whereas in the remaining five the prognosis is good for useful ambulation after correction of deformities. The ability to walk with excellent balance and the good to excellent endurance achieved by twenty-six of these forty-eight paraplegic patients is a manifestation of the superior capacity for performance which is inherent in all children despite severe physical disability.

*Orthopaedic Requirements*

Our second major point is that orthopaedic surgical procedures are indicated much more frequently in paraplegic children than in paraplegic adults. The principal factors responsible for this difference are:

1. In addition to fixed joint contractures, which may occur at any age, deformities in the gross structure of bones and joints are prone to develop in children although they are unlikely to occur in adults. As in poliomyelitis, extensive paralysis during the growing years is a potent cause of skeletal deformities.

2. The presence of easily damaged epiphyses and the relative fragility of the long bones in these children, together with the lack of pain sensation, make so-called conservative treatment of joint contractures by passive stretching likely to be much more hazardous than operative correction.

3. Since nearly all paraplegic children should be regarded as potential walkers, vigorous efforts should be made to prevent and correct deformities which may

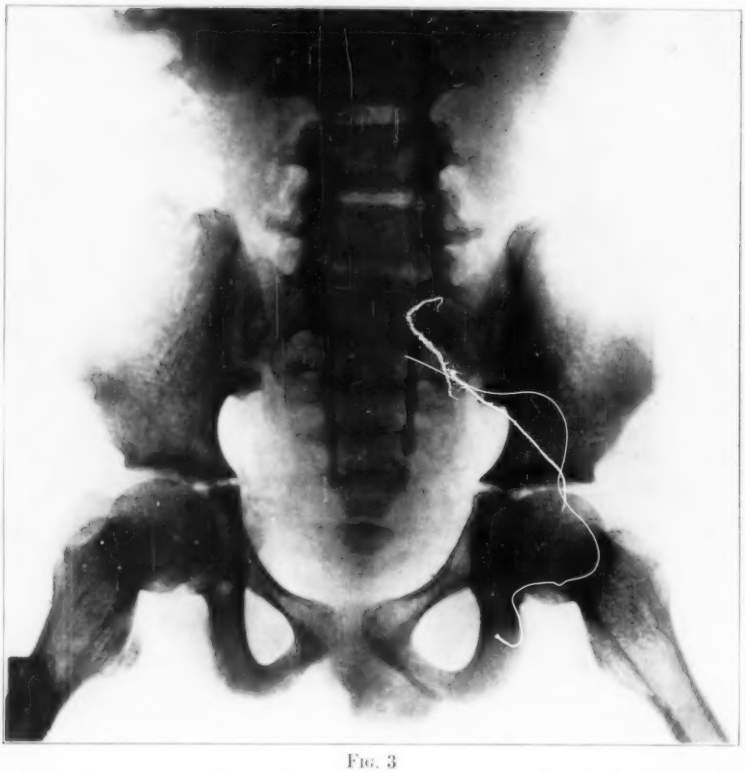

FIG. 3

Typical mid-lumbar and sacral defect: there is a cleft at the third lumbar vertebra and a wide neural-arch defect from the fourth lumbar vertebra through the sacrum.

interfere with walking. Extensive surgery is often fully justified to attain this end.

It is not feasible to review all the varied skeletal deformities for which corrective surgical procedures have been performed, but we will, however, review the operations that have been performed in this series. The number and type of these procedures give some indication of the frequency and type of deformity encountered.

*Spine*

As might be anticipated, paralysis of the spinal musculature of these children causes deformity of the spine. However, the extent of the trunk paralysis is often so short that gross deformity of the trunk does not occur. With higher levels of spinal-cord damage, on the other hand, the extent of the paralysis is sufficient to cause deformities which may become serious clinical problems.

Spine fusion was performed on only three of the forty-eight children with congenital paraplegia. Two children had severe lumbar kyphosis, and one had scoliosis.

Lumbar kyphosis is an unusual deformity in this condition where flexion contractures of the hip commonly cause severe lordosis. The factors leading to kyphosis are not always clear. Both of the patients with lumbar kyphosis had neural-arch defects at high levels (tenth and eleventh thoracic vertebrae) with flaccid paralysis distal to these levels. In one patient posterior subluxation of the third lumbar vertebra developed gradually when the upright position was resumed after an extensive operation for removal of a myelomeningocele (Fig. 7).

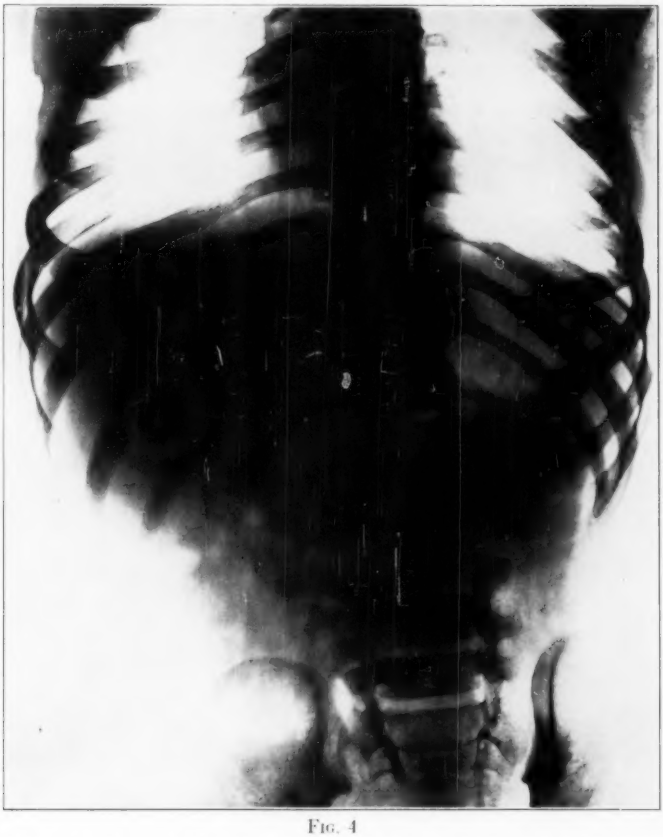

FIG. 4

High-level spina bifida. There is a wide neural-arch defect and widened interpedicular spaces from the eleventh thoracic vertebra distally through the sacrum.

A posterior fusion was attempted by excision of the non-functioning cauda equina, removal of the dislocated vertebra, and internal fixation of the fusion area by staples driven into the bodies of the second and fourth lumbar vertebrae to hold them in apposition. This attempt failed to produce fusion, and a second operation was performed. However, deteriorating kidney function later claimed priority, and the orthopaedic program for this patient was abandoned without achieving fusion.

In the second case we believe that the development of lumbar kyphosis was related to prolonged sitting in a slumped position, with the knees extended so that the contracted hamstrings rotated the pelvis posteriorly, causing flexion and kyphosis of the paralyzed lumbar spine. This patient was successfully treated by spine fusion.

In two patients a transdural approach was used to gain direct access to the vertebral bodies posteriorly; in both, the myelomeningocele had been removed previously and there were no functioning neural structures at the level of the spine fusion.

We believe that surgical fusion of the paralyzed spine will prove to be a much more useful procedure than is indicated by the small number done in our series to date. This belief is based on the observation that in children the paralyzed part of the spine will nearly always become deformed and rigid except in

the lower lesions where the extent of paralyzed spine is short and the deformity may be of no consequence clinically. When paralysis includes the entire lumbar region, and, particularly, when part of the dorsal spine is paralyzed as well, there

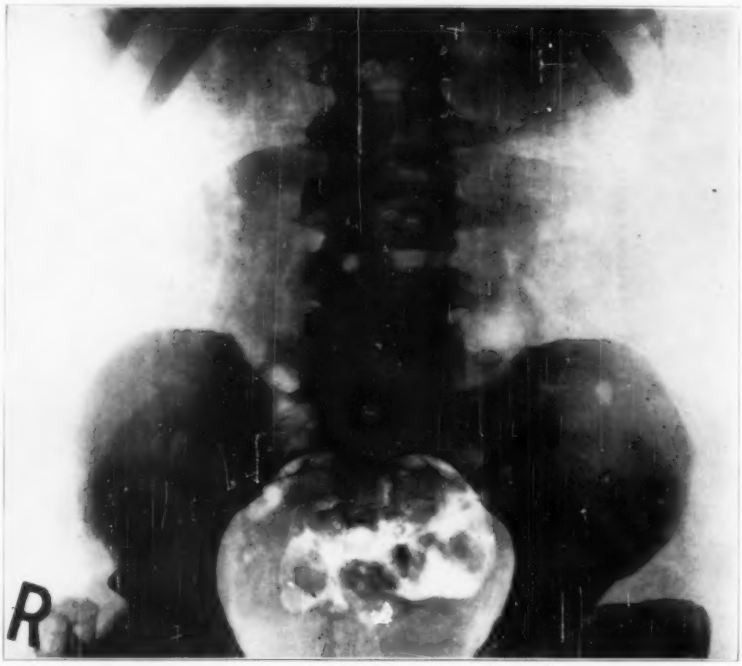


FIG. 5

Neural-arch defects at the second, third, and fourth lumbar vertebrae. Neither the fifth lumbar vertebra nor the sacrum is involved.

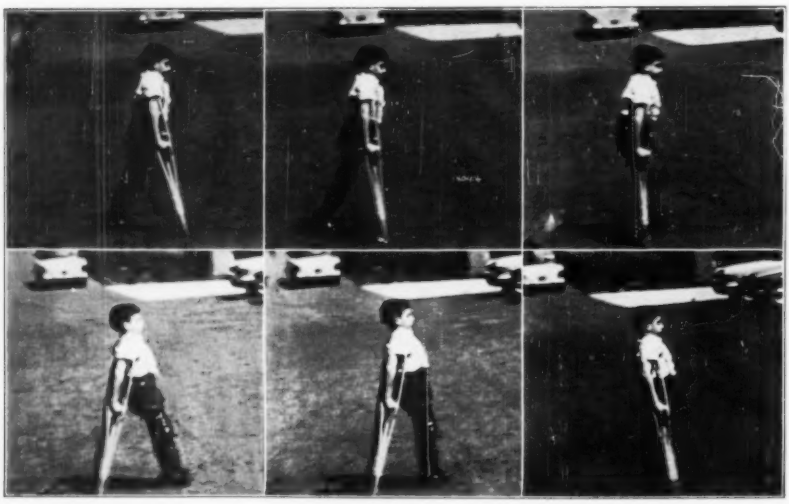

FIG. 6

Swing-through gait as shown by frames from a moving picture. This is a rapid and efficient gait. This patient had bilateral shelf operations (Figs. 9 and 10).

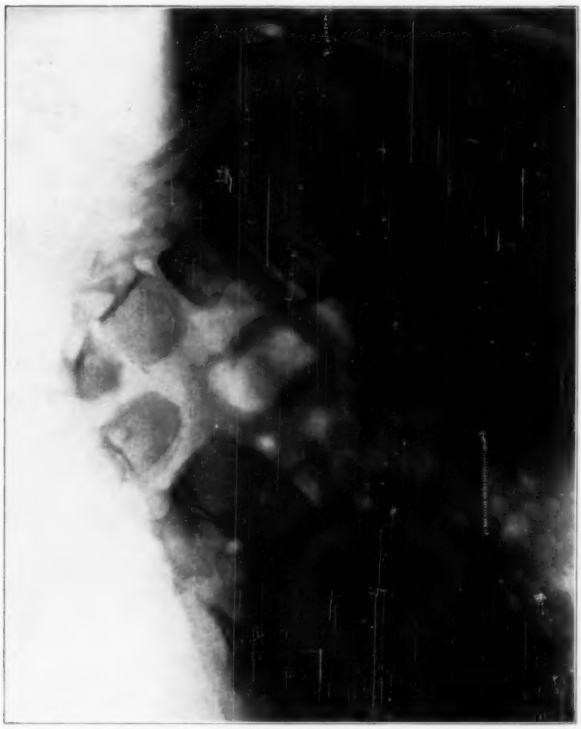

FIG. 7

Posterior dislocation of the body of the third lumbar vertebra following surgical repair of an extensive myelomeningocele—a most unusual complication.

are both functional and structural reasons for believing that fusion is desirable.

Functionally, in crutch-walking the body weight is supported alternately on the feet and on the hands, corresponding to the stance phase and the swing phase of gait. The spine is thus subjected alternately to compression and to tension. During the stance phase the paralyzed spine slumps deeply, whereas in the swing phase a good part of the downward thrust on the hands is dissipated in straightening the spinal slump before the feet can be lifted from the floor. This occurs at every step, so that even if the patient has excellent arm and shoulder musculature he may have a relatively inefficient gait. Structurally, the paralyzed part of the spine tends to become gradually more and more inflexible until finally it is rigid in the position of maximum deformity. When good alignment of the trunk is thus threatened, or when gait is made laborious by a collapsing trunk, spine fusion is indicated as a means of preventing gross deformity or of improving gait.

However, no matter how clear the indications for spine fusion may be in any given instance, the operation should not be undertaken without a full understanding of the difficulties and the hazards, particularly those associated with immobilization. Plaster fixation can be used only with the most meticulous care to avoid localized pressure on any part of the anesthetic skin because of the risk of skin necrosis and sepsis. The conventional method of postoperative immobilization, using a plaster jacket and spica which extends to just above one or both knees, is contra-indicated because of the danger of fracture of the paralyzed leg with or without epiphyseal damage at the level of the end of the cast. This risk can be avoided by extending the spica to the toes, although this exposes a larger

FIG. 8

Unilateral dislocation of the hip in a child with symmetrical paralysis of the trunk and lower extremities. Habitual position must play an important role in the production of such dislocations.

area of anesthetic skin to the danger of pressure necrosis. Prolonged immobilization of a child who has been ambulatory previously also brings with it the hazards of skeletal demineralization, urinary calculi, and pathological fractures in the lower extremities after the fixation is removed. It must be remembered that fractures in anesthetic extremities may not be recognized when they occur. They can be avoided only if great care is exercised when the patient is moved.

The foregoing considerations suggest that if a spine fusion is to be done it should be done early, when good alignment of the trunk can be obtained without the use of forcible correction. Some form of effective internal, rather than external, fixation would be especially advantageous in this class of patients. To date we have had no experience with internal fixation.

*Hip*

Deformities of the hip require correction only if they impair function. Hip-stabilizing operations are needed at times to get equal weight-bearing on both lower extremities, but if both hips are dislocated, weight-bearing may be equal, and function may be very good without corrective surgery. In this series of forty-eight patients there were twenty-seven dislocations and nineteen subluxations of the hip (Figs. 8 and 9). As indicated in Table V, a total of fourteen hip-stabilizing operations was performed.

These derangements of the hip are considered to be paralytic rather than congenital in origin. Conventional methods of treatment for congenital dislocations may prove to be inadequate for the paralytic dislocations in which the acetabulum often is elongated, oblique, and shallow, and the muscle power about the hip is unbalanced or absent. With complete paralysis, there is no muscle power to provide the stability combined with active motion which is the goal of treatment in congenital dislocations. Instead, a state of passive stability is sought, and it is here that the shelf operation has proved useful (Fig. 10). When paralysis of the hip musculature is incomplete, the relatively unopposed action of the flexors and adductors may tend to redislocate the hip. The surgical correction of this condition requires careful judgment because too radical correction of the flexion

FIG. 9

Dislocation of both hips. Note the valgus position of the femoral neck.

FIG. 10

Same patient as that in Fig. 9. Roentgenogram made after bilateral shelf operations to stabilize the hips (Fig. 6).

and adduction deformity by tenotomy and soft-tissue release may compromise the patient's balance in standing and walking. The abductors commonly are paralyzed, and loss of any existing adductor power may leave the patient less stable when standing.

It has been our practice to release flexion contractures of both hips simultaneously. If only one side is released the contracture on the unoperated side tends to rotate the pelvis anteriorly, even in recumbency, thereby flexing the pelvis on the

TABLE VI
SURGICAL PROCEDURES ON THE FEMUR

| Procedure | No. of Procedures |
|---|---|
| Open reduction of fractures | 4 |
| Rotational osteotomy | |
| subtrochanteric | 1 |
| supracondylar | 1 |
| Epiphyseal arrest | |
| Phemister | 1 |
| stapling | 4 |
| | 11 |

TABLE VII
SURGICAL PROCEDURES ON THE KNEE

| | No. of Procedures |
|---|---|
| For flexion contractures | |
| Hamstring lengthening | 11 |
| Hamstring transfer to femur (Eggers) | 3* |
| | 14 |

* Three patients had spotty innervation of posterior thigh musculature. Muscles were functionally ineffective but productive of flexion deformities. The hamstrings were transferred to the femoral condyles to eliminate the deforming force. The results in these three cases were most satisfactory.

femur on the side which has been released. If healing goes on in this position there will be little or no gain from the operation. The double operation is performed by two surgical teams. Each lower extremity is draped separately to permit testing for residual flexion contracture before the operation is concluded. The Soutter technique of release is used, and if the iliopsoas tendon and the joint capsule are deforming factors they are sectioned when necessary, if the muscle is non-functioning. When there is active power in the iliopsoas it may be lengthened, or, if it is unopposed, it is transplanted laterally. Not uncommonly, a whole series of corrective procedures on the lower extremities may be needed. In such cases our preference is to release the hip flexion contractures as the last procedure, allowing the patient to become ambulatory soon afterward. This is desirable because a return to habitual sitting invites recurrence of the hip flexion contractures.

Hip flexion contractures should be corrected when they are severe enough to tilt the pelvis forward and cause extreme lordosis in the upright position. In this situation it is impossible for the patient to straighten up, and he is compelled to keep his crutches always in front of him. As a result, the swing-through gait is impossible.

As Table V shows, release of hip flexion contractures has been one of the most common surgical requirements of these patients. This reflects a preference for surgery rather than for passive stretching of contractures, for the reasons enumerated previously. In addition, if a hip is unstable, flexion contractures cannot be stretched effectively since the attempt to do so will merely lever the unstable femoral head upward.

*Femur*

Pathological fractures have occurred more often than the data in Table VI suggest. On the whole, they are not a great problem. In the group of patients with congenital paraplegia, fifteen have had thirty-one injuries with forty-three bones fractured; prorated against the total hospital time for all forty-eight patients, this averages less than one such injury per nine years of patient-time.

The most useful fact derived from a careful study of these fractures is that

TABLE VIII
SURGICAL PROCEDURES ON THE ANKLE AND FOOT

| | | |
|---|---|---|
| Bone operations | | |
| Triple arthrodesis | 18 | |
| All others | 11 | |
| | | 29 |
| Soft-tissue operations | | |
| Tendo achillis lengthening | 27 | |
| Tendo achillis tenodesis | 2 | |
| All other tendon operations | 11 | |
| | | 40 |
| Total | | 69 |

there is no evidence whatsoever that restriction of activity is indicated as a precautionary measure. We could not find a single instance of femoral or tibial fracture in a child wearing a toe-to-groin brace and having completely unrestricted activity. The quality of bone developed by activity appears to be the best protection against pathological fractures.

*Knee*

The knee, like the hip, demands caution if passive stretching of contractures is to be undertaken; surgical correction is preferable except for minor degrees of flexion contracture. Here, the hazards of passive stretching include epiphyseal damage, supracondylar fracture of the femur, crush fracture of cancellous bone of the proximal portion of the tibia, and subluxation of the knee.

As shown in Table VII, all of the surgery on the knee in this series of patients was required for correction of flexion contractures.

Absent or reduced sensation at the knee should usually be regarded as a contra-indication to passive stretching of contractures. In the absence of warning pain, passive stretching is likely to cause soft-tissue trauma unless done most skillfully. After such trauma, dense connective tissue is formed during the process of repair which makes the contractures even more resistant to passive stretching.

*Tibia*

Osteotomy of the tibia was done seven times. Five of these operations were rotational osteotomies through the proximal part of the tibia to correct torsion, and two were supramalleolar osteotomies to correct extreme valgus deformities at the ankle.

*Ankle and Foot*

The paralyzed feet in this series presented a great array of deformities, including various combinations of equinus, varus, valgus, cavus, and adduction of the fore part of the foot, as well as calcaneus and rocker-bottom deformities.

Here again deformity *per se* is not an indication for corrective surgery. A foot which permits good balance during weight-bearing and does not require specially made shoes and in which localized skin pressure does not develop is the goal. Although arthrodesing operations were often performed in this series (Table VIII), passive mobility should not be sacrificed needlessly, especially at the ankle and in the fore part of the foot. This flexibility is useful in preventing localized skin pressure during weight-bearing and undue stress on the metatarsals which might cause fatigue fracture.

The data in Table VIII suggest that the most useful operations about the foot and ankle have been triple arthrodesis and lengthening of the Achilles tendon. The simple subtalar arthrodesis described by Grice was done recently in selected patients, but these cases are not included in Table VIII.

TABLE IX
CAUSES, AGES, AND LEVELS OF ACQUIRED PARAPLEGIA

| Cause | No. of Patients | Age at Onset of Paralysis (*Years*) | Level of Paralysis |
|---|---|---|---|
| Trauma | | | |
| Birth injury to spinal cord | 2 | Birth | T3–4, T12 |
| Struck by car | 2 | 3, 15 | T5, T3–4 |
| Surgery (spine fusion) | 1 | 9 | T7 |
| Falling sand | 1 | 11 | T10 |
| Falling lumber | 1 | 12 | T12 |
| Bullet wounds | 2 | 14, 17 | L5, L2–3 |
| Fall from a height | 3 | 15, 15, 15 | T7, T10, L1 |
| Dive into shallow water | 1 | 16 | T3–4 |
| Total (due to trauma) | 13 | | |
| Infections | 3 | 5, 14, 15 | T10, T4, T5–6 |
| Intraspinal vascular anomalies | 1 | 15 | L1 |
| Total | 17 | | |

TABLE X
SPINE AND HIP SURGERY FOR ACQUIRED PARAPLEGIA *

| | | |
|---|---|---|
| *Spine* | | |
| | Fusion of paralytic spine | 4 |
| | Abdominal fascial slings | 1* |
| | | 5 |
| *Hip* | | |
| | Stabilizing procedures | |
| | Iliopsoas tenodesis | 2** |
| | Mobilizing procedures | |
| | Arthroplasty | 3 |
| | Jones pseudarthrosis | 2 |
| | Release of flexion contractures | 9 |
| | | 16 |

* Criss-crossed fascial strips were placed from the anterior superior spines into the contralateral tenth ribs in an attempt to control severe lumbar lordosis and anterior pelvic tilt. Sepsis resulted and the procedure failed to obtain the desired result.

** Indication for procedure was the correction of a severe paralytic hyperextension of both hips with an associated lumbar kyphotic slump in a patient with a high-level flaccid paralysis. Bilateral iliopsoas tenodeses blocked the hips in neutral extension resulting in a spectacular improvement of trunk control. A five-inch increase in standing height was obtained.

ACQUIRED PARAPLEGIA

A parallel review was made of seventeen children whose paraplegia was acquired. The data in Table IX show the cause of spinal-cord damage, the age at onset, and the level of paralysis.

*Prognosis*

*Life Expectancy*

One patient in this group died at the age of twenty-one, seventeen years after the onset of paralysis. The remaining sixteen are living. Their ages range from seven to thirty years, the average age being 21.3 years. The duration of paralysis in these patients is one and one-half to thirty years, with an average duration of 9.2 years. Three of these patients are thirty years old, and six are between twenty-two and twenty-seven years of age. Among the nine older patients the average

TABLE XI
SURGERY ON THE LOWER EXTREMITY FOR ACQUIRED PARAPLEGIA

| Site | Procedure | No. of Procedures |
|---|---|---|
| Femur | | |
| | Rotational osteotomy | 1 |
| Knee | | |
| | For flexion contractures | |
| | Hamstring tenotomy and capsulotomy | 2 |
| | Hamstring transfer to femur (Eggers) | 1* |
| Ankle | | |
| | Gastrocnemius recession | 1 |
| | Tendo achillis lengthening | 6 |

* Indication for this procedure was spasticity of the hamstrings producing a flexion deformity of the knees. Result was a definite improvement so that it was possible to fit the patient to toe-to-groin braces.

TABLE XII
PRESENT STATUS OF TEN LIVING FORMER PATIENTS, EIGHT TO EIGHTEEN YEARS OF AGE

| Status | No. of Patients |
|---|---|
| Attending school | 4 |
| Home teacher | 1 |
| Not in school | 2 |
| In other institutions | 3 |

TABLE XIII
PRESENT STATUS OF SIXTEEN LIVING FORMER PATIENTS, NINETEEN TO THIRTY YEARS OF AGE

| Status | No. of Patients |
|---|---|
| Total self-care and total self-support | 6 |
| Total self-care and partial self-support | 4 |
| Total self-care (senior in college) | 1 |
| Total self-care, but unemployable | 3 |
| In other institutions | 2 |

period of survival since the onset of paraplegia at the time of writing is 13.7 years.

Although no conclusions as to the total life expectancy can be drawn at this time, the average length of survival since onset in these seventeen patients has been surprisingly long.

*Ambulation*

The group with acquired paraplegia has not made quite so good a record in learning to walk as the group with congenital paralysis. Of the sixteen living patients, eight have an efficient pull-to or swing-through gait, using toe-to-groin braces and crutches, two are still in training, and six are not walking.

*Orthopaedic Surgery*

The requirements for orthopaedic surgery in the group with acquired paraplegia have been considerably less than in the group with congenital paraplegia. We believe that this is due largely to relative maturity of the skeleton before the onset of paralysis. As is indicated in Table IX, ten of the children reached the age of fourteen years or older before paralysis occurred.

Spine fusion was done in four of seventeen patients as compared with three

TABLE XIV

STATUS OF PARAPLEGIC FORMER PATIENTS OVER EIGHTEEN YEARS OF AGE AS OF MARCH 1, 1958

| Patient | Sex | Age at Onset of Paraplegia | Spinal-Cord Level | Cause of Paraplegia | Left Mass. Hospital School (*year*) | Education and Length of Vocational Training | Career | Economic and Social Status | Able to Drive Car |
|---|---|---|---|---|---|---|---|---|---|
| *A. Employed* | | | | | | | | | |
| P. A. | M | Birth | L2 | Myelomeningocele | 1950 | Grade 9; watch repair, 1500 hours | Electronics; production worker, relays | Total self-support; married | Yes |
| G. F. | M | Birth | T12 | Birth injury of cord | 1950 | Grade 9; Museum School of Fine Arts, 4 yrs. | Gem cutter, art teacher, free-lance artist | Total self-support; single | No |
| D. G. | M | 14½ yrs. | L5 | Bullet wound | 1950 | Grade 10; watch repair, 800 hours | Electronics; supervisor of 21 employees | Total self-support; married; one child | Yes |
| J. D. | M | Birth | L3 | Myelomeningocele | 1951 | Grade 10 | Electronics; production worker | Total self-support, 5 yrs. (died, 1957) | Yes |
| R. J. | M | 17 yrs. | L2–3 | Bullet wound | 1951 | High school; watch repair, 2500 hours | Watch repair; own business | Partial self-support; single | Yes |
| A. S. | M | 15½ yrs. | T5–6 | Infection | 1951 | Grade 8; watch repair, 2500 hours | Own business; watch repair and variety store | Nearly total self-support; single | Yes |
| R. W. | M | Birth | L4 | Myelomeningocele | 1951 | High school; watch repair, 300 hours | Electronics; production worker | Total self-support, 2½ yrs. (died, 1955) | Yes |
| H. D. | M | 16 yrs. | T3–4 | Dive into shallow water | 1952 | High school; watch repair, 1480 hours | Succession of jobs; watch repair and selling | Partial self-support; single | Yes |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| S. L. | F | Birth | L5 | Myelomeningocele | 1952 | High school; junior college | Telephone order solicitor | Partial self-support; single | No |
| N. D. | M | 15 yrs. | T7 | Fifty-foot fall from power-line tower | 1954 | High school; entered University of Massachusetts, 1954 | Senior in college * | Married | Yes |
| T. O'B. | M | 15½ yrs. | L1 | Intraspinal Spinal vascular anomalies | 1954 | High school; postgrad. business and drafting courses | Electronics; chief of drafting department | Total self-support; single | Yes |
| F. P. | F | Birth | L5 | Myelomeningocele | 1956 | High school | Secretary | Total self-support; single | No |
| A. W. | F | 15½ yrs. | T10 | Forty-foot fall through skylight | 1957 | High school | Cashier | Total self-support; married | No |
| *B. Unemployed* | | | | | | | | | |
| J. P. M. | M | 15½ yrs. | L1 | Forty-foot fall from roof | 1949 | Grade 9 | Unemployed | Receiving disability assistance; living alone; single | No |
| M. O'C. | F | Birth | L1 | Myelomeningocele | 1949 | Ungraded (below grade 8) | Unemployed | In a state hospital; custodial care | — |
| D. W. | M | Birth | L5 | Myelomeningocele | 1952 | Grade 9 | Unemployed | Part-time work as piano player; living at home; single | — |
| J. M. | M | Birth | L1 | Myelomeningocele | 1955 | Grade 8 | Unemployed | No gainful occupation; living at home; single | — |
| T. T. | M | 3 yrs. | T5 | Struck by car | 1955 | High school; watch repair, 1000 hours | No work record | Died 10 mos. after discharge | — |
| M. C. | F | 5 yrs. | T10 | Infection | 1956 | High school | Unemployed | In a state hospital; custodial care | — |

* Became high-school teacher of mathematics, 1958–1959.

fusions in forty-eight patients with congenital paraplegia. With higher levels of paralysis, trunk stability is a most important requirement.

As already indicated, the outlook for the development of an efficient paraplegic gait with good balance and endurance is much better in children than in adults, but adults enjoy relative freedom from intrinsic skeletal deformities secondary to paralysis. From these facts it might be inferred that children who are older at the onset of paraplegia should have the advantages of both groups—sufficient skeletal maturity to escape the gross deformities which develop in the younger paraplegics with retention of the superior potential for function characteristic of childhood. In our limited experience this appears to be so. The relatively small number of corrective surgical procedures listed in Tables X and XI lends support to this theory.

## OTHER FACTORS AFFECTING REHABILITATION

Although this paper is concerned with the orthopaedic aspects of the treatment of paraplegia in children, there are other important factors that enter into the total rehabilitation of these children. Urological and nursing care, physical therapy, neurosurgery and general surgery, as well as formal education and vocational training, are all important to life, health, function, and the achievement of a gainful occupation; these activities are not ancillary but essential in their respective spheres. However, these components of the rehabilitation program are beyond the scope of this paper.

## FOLLOW-UP STUDY

Of the sixty-five paraplegic patients reviewed here, thirty-five left the Massachusetts Hospital School; of these, eight died and one could not be traced, leaving twenty-six living former patients available for follow-up study. This study was carried out by a qualified social worker, who knew the patients and who made individual home visits to determine in detail the present status of each living former patient.

Among the eight patients who died, seven autopsies were performed. The primary cause of death common to all eight was chronic pyelonephritis with uremia. Additional causes of death included arterial hypertension in two, renal rickets in two, homologous serum jaundice in one, amyloidosis in one, and duodenal ulcer with hemorrhage in one.

The study was concerned primarily with determining how successful these patients have been in developing total self-sufficiency. Consequently, they were divided into two groups according to age; those aged eighteen years and younger were considered to be still in the formative years, whereas those over eighteen years were considered to have arrived at an end result.

In Table XII the present status of former patients in the younger age group is summarized. No findings as to self-sufficiency are presented because these patients have not yet reached a functional end result, but all of these children have achieved various degrees of self-sufficiency.

The later courses of former patients who are, at the time of writing, between nineteen and thirty years old are summarized in terms of self-sufficiency in Table XIII.

Despite some failures, the majority of former patients have impressive work records, considering their severe degrees of physical handicap. The life histories of all nineteen former patients with paraplegia over the age of eighteen are summarized in Table XIV; this table includes three who died as well as the sixteen who are still living.

Some facts supplementing Table XIV are of interest. The independence, once it is achieved by these young paraplegics, appears to be permanent. No member of the gainfully employed group (A) has regressed to the dependent group (B). Those working in electronics were employed by three different companies. The

information concerning the use of a car is included because competitive employability requires not only knowledge or skill but also a means of getting to and from the place of employment; the cars, of course, have to be equipped with hand controls.

*Comment*

It is reasonable to anticipate that in the future there will be an increasing number of paraplegic patients, particularly in the young age groups. The reasons for this prediction are:

1. In the patients with congenital paraplegia a very modest success by the medical profession in solving the crises of early life could easily double the number of patients who survive infancy because at present the percentage of survivors is small;

2. In patients with acquired paraplegia there is at present no prospect of a reduction in the number of injuries that cause paraplegia, but it is probable that the number of survivors from such injuries will gradually increase;

3. In both groups, increasing initial survival and increasing average longevity will have a cumulative effect, and more such patients will be alive at any given time.

It seems reasonable to conclude from our review that large numbers of paraplegic children are likely to survive well into the years of adult life. It is our conviction that resources and skills now available make the rehabilitation of such children a practical endeavor and that the objective should be total economic and personal self-sufficiency. A fully independent patient is much more likely to be happy and well adjusted to his disability than one who is dependent. It is hoped that more interest will be developed in paraplegic children and in their needs for comprehensive care and also in the problems which still remain to be solved. In this endeavor the interested orthopaedic surgeon should assume leadership of the integrated team effort which is essential to carry these patients through to physical and economic self-sufficiency.

REFERENCES

1. Bluestone, S. S., and Deaver, G. G.: Habilitation of the Child with Spina Bifida and Myelomeningocele. J. Am. Med. Assn., **161:** 1248-1251, 1956.
2. Eggers, G. W. N.: Transplantation of Hamstring Tendons to Femoral Condyles in Order to Improve Hip Extension and to Decrease Knee Flexion in Cerebral Spastic Paralysis. J. Bone and Joint Surg., **34-A:** 827-830, Oct. 1952.
3. Grice, D. S.: An Extra-Articular Arthrodesis of the Subastragalar Joint for Correction of Paralytic Flat Feet in Children. J. Bone and Joint Surg., **34-A:** 927-940, Oct. 1952.
4. Grice, D. S.: Further Experience with Extra-Articular Arthrodesis of the Subtalar Joint. J. Bone and Joint Surg., **37-A:** 246-259, Apr. 1955.
5. Jaeger, R.: Congenital Spinal Meningocele. J. Am. Med. Assn., **153:** 792-795, 1953.

# Emotional Maladjustment in the Surgical Correction of Long-Standing Deformity

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Apart from the purely physical aspects of sickness, many emotional factors are involved. In chronic sickness, particularly, there is a need for emotional adaptation. The patient's personality and his previous adaptation to his environment are involved in the success of his emotional adjustment to his illness.

A person who has suffered a physical deformity over a period of many years must, to some degree, have adapted himself to his disability. After correction by surgery, there is no doubt that he will be faced again by a need for emotional readjustment.

Mass immigration into Israel brought under the care of its social services many people who had never, previously, enjoyed any medical care. Some of them, crippled by disease or accident, had lived on charity in their country of origin by exploiting their physical deformities. In their new environment the exploitation of their physical deformities was not socially acceptable, and the possibility of surgical correction became practical.

In the three cases reported here, the patients had suffered from long-standing deformities which were corrected surgically with physically satisfactory results. These patients did not seek treatment on their initiative but were referred by welfare authorities. However, they willingly accepted surgical intervention.

In each patient, postoperative emotional reactions were manifested, ranging from resistance, anxiety, depression, and, even, severe psychosis, which were unexpected and which revealed the inability of the patients to adapt themselves to their new situation.

CASE 1. A woman, forty-seven years old, had immigrated to Israel from Iraq four years prior to admission. At the age of seventeen, she was severely burned about her right knee, a severe knee-flexion contracture being produced. She moved mostly by crawling, although she was able to walk erect with makeshift crutches. Her attitude was cooperative, even though communication took place through an interpreter as she understood only her native language.

Examination revealed that she was blind in her right eye as a result of trachoma. The right lower extremity was shorter than the left by three centimeters. There was a marked atrophy of the thigh muscles. In the heavily scarred knee there was flexion contracture of 40 degrees (Fig. 1). At the hip there was a flexion contracture of 35 degrees, and an abduction contracture of 25 degrees. A compensatory scoliosis had developed. Roentgenographic examination of the knee showed destruction of the joint with severe osteoporosis (Fig. 2).

On November 11, 1955, compression arthrodesis of the knee joint was performed. The skin defect, created at the popliteal space after straightening the knee, was covered by a split-thickness graft. A month later, release of the abduction contracture of the hip was performed. Because of the osteoporosis, the compression pins cut through the fragile bone and reduced the effectiveness of the compression; the patient had to remain in a spica cast for three months. During this entire period, she was cheerful and cooperative, looking forward hopefully to the day when she would be able to stand and walk erect. When the cast was removed, clinical and roentgenographic examination showed solid union of the arthrodesis.

The patient, naturally weak and unsteady on her feet, was at first quite cooperative, but two days later cooperation suddenly ceased. She became negativistic, mute, refused to eat or drink, and after five days had to be transferred to the psychiatric unit.

Because of the lack of a common language, a regular psychotherapeutic approach was not possible, but she was treated with kindness and understanding. Over a period of four weeks she received two electroconvulsive shock treatments and was nourished chiefly by intravenous

fluids. Finally, she came out of her mutist state. After this deadlock was broken, slow headway became possible, especially when it was understood that she would now eat only her native food. She seemed to like the physiotherapist, and began to cooperate; she started to stand and later to walk, and accepted the fact that she still had a stiff knee, although it was straight (Figs. 3 and 4).

The patient now walks freely but with a slight limp. She now undertakes household chores at her sister's home. She is cooperative and visits our follow-up clinic regularly. However, she seems to be disappointed with the final surgical results.

FIG. 1

FIG. 2

Fig. 1: Case 1. Preoperative photograph showing flexion contracture of the right knee due to scar over the popliteal fossa.

Fig. 2: Preoperative roentgenogram showing destruction of the knee joint in a flexed position.

CASE 2. A man fifty years old, born in Iraq, immigrated to Israel five years prior to being referred to the orthopaedic out-patient clinic. At the age of sixteen he had suffered a bullet wound through his left knee, complicated by severe septic arthritis. He had had some schooling and could read and write Arabic as well as Hebrew. He earned his living as a small shopkeeper at a house entrance.

Examination revealed the left limb to be five centimeters shorter than the right. There was no limitation of movement of the hip joint. The left knee was ankylosed at 120 degrees. The ankle was in equinus deformity of 120 degrees, with almost no movement. He walked with a limp but without pain. Roentgenograms showed osteoporosis of the whole limb with solid bony ankylosis of the knee.

The patient seemed perfectly adapted to his deformity. The limp did not bother him unduly as he had no pain. He even displayed his crippled leg prominently while in his shop and considered it a good advertisement. Operation and correction of the deformity were indicated purely from an orthopaedic point of view. This possibility was discussed with the patient. On October 9, 1955, a supracondylar osteotomy was performed to eliminate the knee flexion and on December 5, 1955, elongation of the tendo achillis was carried out. The outcome of the operation was satisfactory.

Probably on the basis of a lifelong phantasy as to what he would do if his leg were normal, the patient sold his shop at a low price without consulting his family. During the time that his leg was in a cast he lived on the capital he had received from the sale of his shop and was in a good mood.

Trouble began when the cast was removed. Clinical and roentgenographic examination showed union of the osteotomy; the surgical result was judged satisfactory. The patient,

however, could see that his left leg still remained shorter than the right, and he continued to limp. At a considerable financial loss he arranged for the purchaser to resell his shop to him, but he was no longer satisfied with his work. He complained that his turnover was much smaller after the operation because now that his leg was straight he drew less attention from the passer-by.

He began to complain of severe pain, refused weight-bearing and gait training, and did not want to discard his crutches. He repeatedly complained to the surgeon that his preoperative state had been by far the more preferable. He developed a state of invalidism and

FIG. 3

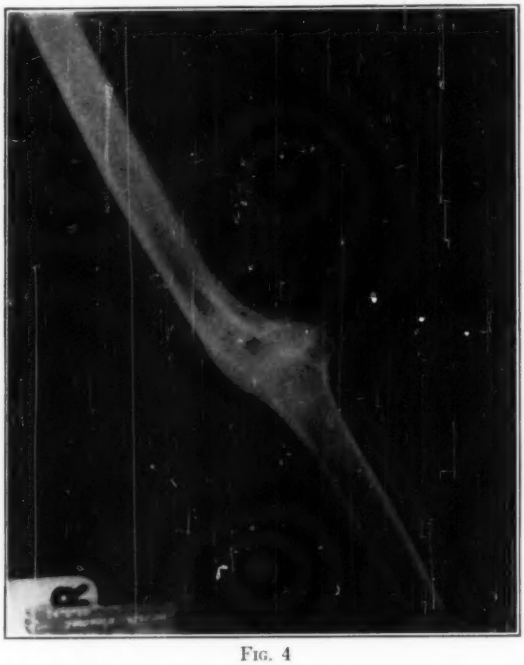

FIG. 4

Fig. 3: Postoperative photograph showing the contracture corrected.
Fig. 4: Postoperative roentgenogram showing solid bone union following compression arthrodesis.

stayed away from his work for a long period. Only after considerable effort on the part of the social worker and surgeon did he agree to resume work and to attend regularly to his business.

The patient continues to visit our out-patient clinic, complaining of pain around the operative site—pain not related to any other system. At the same time he accuses and reproaches the physicians for not having kept their promise.

CASE 3. A young man, twenty-five years old, had been crippled since the age of three as a result of poliomyelitis. He had but minimum schooling and made his living as a beggar selling postcards at a church gate. A tourist, taking pity on his disability, had the young man referred to the orthopaedic department. He was admitted for treatment, but his mentality, background, and his expectation from the surgical intervention were not thoroughly investigated.

On examination, it was found that he could walk only with the aid of crutches or by stabilizing his left knee with his hand. The left limb was seven centimeters shorter than the right. The hip joint was essentially flail with a 35-degree flexion contracture. An old surgical scar indicated a previous attempt at relieving this contracture. At the left knee joint there was a flexion contracture of 40 degrees with a range of movement between 140 and 90 degrees and an associated paralysis of the thigh muscles. The calf muscles were normal, and there was no ankle deformity. Roentgenographic examination showed marked retardation in the development of the left pelvis, with anteversion and coxa valga of the femoral neck.

The patient underwent a series of operations. Hip flexion release and supracondylar osteotomy were performed on August 29, 1956, followed by arthrodesis of the hip on October 22, 1956. Three months after the last operation, when the cast was removed, a fracture occurred

at the site of the osteotomy. This necessitated the further operation of open reduction and internal fixation.

The cast was removed on June 5, 1957, eight months after commencement of surgical treatment. Clinical and roentgenographic examination confirmed solid union. However, his limb remained atrophied and short, the only improvements being a stable hip and a straight knee, with limited motion after the supracondylar osteotomy and refracture.

The patient realized that his expectations were not fulfilled, and during the days following removal of the cast, the patient would let no one touch him, claiming that he was in severe pain. The patient became uncooperative, and it was impossible to get him out of bed. It took two weeks for the patient to adjust himself to his disappointment; after much persuasion he finally got out of bed and started to walk.

He now walks steadily; and, although he has a marked limp, there is much improvement as compared with his original condition. The knee does not require any brace, as the hip fusion and the plantar flexors of the foot stabilize the knee in extension as he walks. He, however, continually declares his disappointment, claiming that he was better off before the operation.

## DISCUSSION

The three cases just described represent a special category within the vast community of handicapped people. These patients had accepted their infirmities as natural phenomena, in the full conviction that nature was their master. Moreover, their low social status and the cultural patterns of their surroundings permitted them to exploit their infirmities for their livelihood. Two of them openly complained that their income had been adversely affected by the operation. None was initially satisfied with the result of the intervention, which from the surgical point of view was considered successful.

If we search for reasons for their reactions, we find, as a common factor, that none of these patients sought treatment on his own initiative. They were referred by a third interested person who persuaded them to undergo surgical intervention. They, thus, actually put the responsibility for their future into the hands of those who influenced them to change their accustomed pattern of living. Only from their complaints, when the results of the operations became clear, was it realized that the explanations initially given to the patients were not sufficiently well understood. Although it is true that the patients had formally agreed to the operation by a nod of the head and a signature of a thumbprint, this did not mean, however, that they had actually realized what was the change to which they were consenting.

The handicapped patient, like any other person, has in his mind a certain body-image of himself [4]. Grayson found that in so far as a deformity is accepted by a patient, this deformity is integrated into his body-image. The acceptance of a handicap, however, does not mean giving up hope that it may one day be cured, and many invalids nurture phantasies as to how they would look and act if only they were whole and healthy. It is these phantasies that in a certain way help many of them to go on struggling in their daily life.

When an operation is advised, there may be a wide gap between a rational understanding of the results to be anticipated and the phantasies with which the handicapped person has previously lived. In such phantasies there is as a rule no place for failure; these patients feel so underprivileged by fate that for them an operation seems a gateway to happiness. The three case reports presented show how greatly a patient may be disappointed when the results of surgical intervention, although objectively quite satisfactory, do not conform with his phantasies.

It was perhaps possible to comprehend partly the form of these phantasies in two of the patients. The first patient, while still in the plaster cast, told the nurses of her intense desire to marry. Her neighbors said that she had previously always refused an operation, but when a blind beggar asked her to marry him she was only prepared to do so after a cure by operation. The second patient did not reveal his actual plans, but the rash and impulsive sale of his business, prior to the operation, suggests that he considered this source of income a very poor second compared with what he would achieve once he was able to walk erect. It was

fortunate enough, and a credit to his basically strong personality, that he was later able to admit failure and to return to his former business, even though he still bears a grudge against the doctors.

However, not only hopes are raised but fears too are aroused when an operation is suggested to a crippled person. By integrating the deformity into his body-image, the patient has attained an emotional equilibrium within himself. In addition, the invalid lives in an environment that takes care of him, usually the family or an institution, even though he may be earning his living or providing for others. He feels dependent on this care and may consider the bonds created by it to be his most precious possession. There may exist an apprehension that through surgical intervention he would have to give up this particular relationship, for he himself, as well as the outer world, might consider that he is no longer entitled to special treatment. He might even fear that he will be abandoned by those who up until now have taken care of him and that the physical freedom attained will not be worth the emotional loneliness anticipated. Thus, some patients confronted with the decision to undergo physical correction of deformity face a conflict between the desire to restore the integrity of the body, and the fear of giving up their emotional security and dependence. It is increasingly recognized that these emotional factors greatly affect the outcome of an operation and the rehabilitation process. The surgical intervention may be too abrupt and does not always allow for progressive adaptation to the new situation.

In the three patients, these hopes and fears were not brought out openly, and it remains doubtful to what degree this would have been possible, in view of their low intellectual level and different cultural patterns. Thus, when confronted with a new reality for which they were not prepared, they reacted violently when they realized that there was a wide discrepancy between the actual situation and their phantasies. The result of this reaction was an accentuation of their helplessness and an attempt to revert to the dependent situation in which they had previously felt more at ease.

## REFERENCES

1. Grayson, Morris, and Russek, A. S.: Rehabilitation, Orthopaedics and Psychiatry. *In* Psychology of Physical Illness. Edited by L. Bellak. New York, Grune and Stratton, 1952.
2. Grayson, Morris: Concept of "Acceptance" in Physical Rehabilitation. J. Am. Med. Assn., **145**: 893-896, 1951.
3. Grinker, R. R., and Spiegel, J. P.: Men under Stress. New York, Blakiston, 1945.
4. Schilder, Paul: The Image and Appearance of the Human Body. New York, International Universities Press, 1950.

# Fundamental Aspects of Muscle Function*

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In being invited to address the annual meeting of the American Orthopaedic Association, I am well aware that this invitation is not based on any expectations regarding my knowledge in the orthopaedic field. On the contrary, it expresses an awareness on your part that within a meeting largely devoted to the discussion of specialists' topics, there will be place for an occasional reflection of a somewhat more general nature. For such a purpose a discussion on contemporary muscle physiology seems well selected not only because muscle is the shortest way to a man's bones, but also because muscle is a tissue from which very much knowledge of a general nature is derived, its study traditionally having been one of the most advanced chapters of physiology. Over a century ago it contributed much to the foundation of our knowledge of force and energetics; it has continued to be in the forefront of scientific advances, and currently it again plays a leading role in the formation of our concepts on the nature of excitation and on the molecular mechanisms of vital activities. My discussion of muscle will be wholly on this scientific level, taking it for granted that such increased theoretical knowledge will sooner or later also be of direct medical and surgical benefit.

I can best introduce the full scope of our problem by a simple description of what happens when muscle motion is initiated. A motor impulse arrives along a nerve and is transmitted onto the muscle and conducted alongside it. This impulse then activates the inside of this muscle cell and causes such changes that the fibrils first develop tension or shortening and then effect the opposite. Each of these brief sentences conceals biological problems of vast magnitude. We will try to get a brief glimpse of each of those and to gain some impression of our current knowledge concerning them. I wish to be very brief on the first point. When a nerve impulse arrives at the neuromuscular junction it results in the release of a number of packages of acetylcholine which diffuse across the junctional space and react at the muscle part of the myoneural junction with a receptor structure. This in some way causes an end-plate potential to be set up. If the potential exceeds a critical magnitude, the adjacent parts of the muscle membrane are depolarized and depolarization then speeds along this membrane as a propagated impulse, successively exciting the entire length of the fiber. It is from this point that we shall start our inquiry (Fig. 1).

According to the classic concept, stimulation is an event in the surface membrane of the excitable cell. This concept is occasionally questioned and we shall be wise to follow with interest the efforts of those who are working on alternate hypotheses; for example, there are investigators who try to explain irritability and ion distribution in terms of charge effects in the cell's interior [17]. Nevertheless, it will be most fruitful for the moment to stay with the classic theory and look upon excitation as a membrane effort. From the investigations of Hodgkin [10,11], this membrane event appears to consist of specific changes in permeability or conductivity for certain ions such as sodium, potassium, and calcium, which, in a manner not to be discussed in this brief context, account for both the propagation of the impulse and its electrical manifestation in the form of an action potential. What is less understood is the mechanism by which such a surface

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change may result in a sudden activation of the entire interior of the cell, and, indeed, we cannot say much else than that this does seem to happen. Once excitation occurs, it has two kinds of consequences. On the one hand the contractile structures are thrown into mechanical activity; on the other hand, there is a concomitant increase in metabolism. These metabolic changes are intimately associated with the mechanical events because mechanical activity will derive its energy from associated metabolic reactions. However, we are as yet unable to decide whether the mechanical changes come first and somehow elicit the biochemical events for which they have a need, or whether the chemical changes are first elicited and cause the mechanical activity to follow. It may even be that neither one causes the other, but that the cellular mechanisms are clever enough

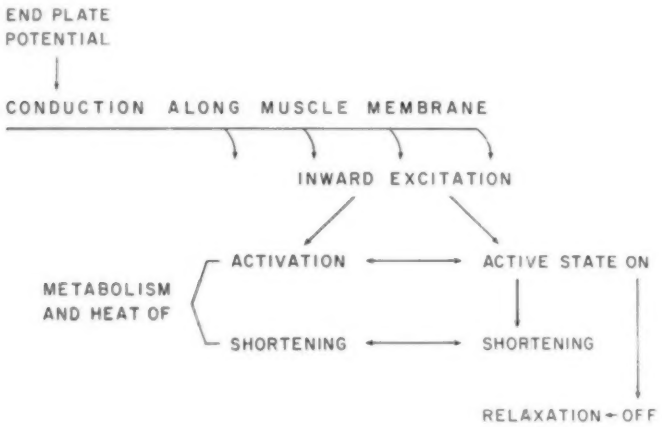


FIG. 1

Scheme of some of the possible links connecting stimulus and response in muscle. This diagram aims to demonstrate that the inward spread of the excitatory process leads to mechanical as well as chemical responses. The latter have been specifically investigated by means of heat measurements, which have shown that a certain release of metabolic energy is required to activate the responsive structures, while additional heat is liberated proportional to the shortening that occurs. These portions of energy are known as activation heat and shortening heat and must be due to separately released quantities of metabolism. Actual knowledge concerning the nature of the connections between the various processes is practically absent.

to see to it that on excitation both categories of events are independently called upon in about the right proportion. One experimental approach to this dilemma might be an attempt to find ways of uncoupling these two responses in such a fashion that we can obtain the one without evoking the other in order to gain a clear insight into their mutual causal relationships. Attempts of this sort have been recently initiated by Hodgkin and also in my own laboratory and I will indicate some of the preliminary results.

According to a recent experiment by Hodgkin and Horowicz [12], it is possible to maintain the excitability of a muscle which is kept in concentrated saline. Under those conditions the muscle remains capable of conducting a normal impulse, but excitation is not followed by mechanical activity. Yet, as was demonstrated by Hill [7] by means of heat measurements, these muscles in concentrated saline do develop the activation energy which normally is strictly correlated with mechanical activity. This indicates that under these conditions the chemical changes usually associated with activity do take place. Another type of experimental approach consists in the demonstration that when muscles are placed in salt media with an increased potassium content, they show a greatly enhanced metabolism comparable to what is found under normal conditions in conjunction with mechanical activity [8].

However, this enhanced metabolism in the presence of potassium is not associ-

ated with any such mechanical activity except, perhaps, in the first few seconds. Both types of evidence show conclusively that it is possible, either by means of stimulation or by means of other experimental changes acting upon the cell membrane, to elicit an increase of metabolism without causing mechanical change. This would indicate that either excitation results primarily in an activation of metabolism which in turn causes mechanical activity, but in a way which can be experimentally uncoupled, or that excitation causes independently an activation of metabolism and of mechanical activity in such a way that we can uncouple the latter while keeping the former connection intact. We are currently engaged in an

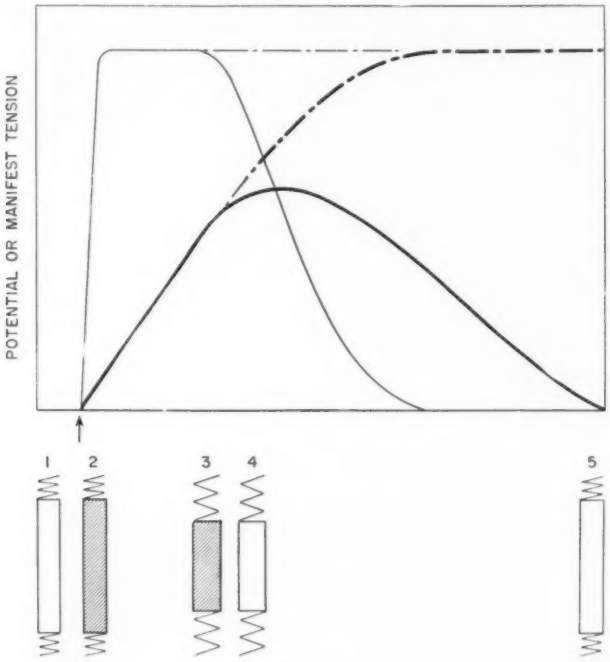


FIG. 2

Schematic presentation of a muscle twitch and of the underlying phenomena. The heavy, solid curve gives a record of an isometric twitch in terms of tension (ordinate) developed as a function of time (abscissa). The light curve gives the corresponding development and decay of the active state. The broken curves represent tetanic stimulation in which the active state is maintained throughout the represented time interval. Below, schematic presentation of the contractile component (rectangle, blank in rest, shaded during the active state) and of the series elastic component (drawn as an extendable spring).

intensive investigation of these matters, but inasmuch as the understanding of the regulation of cell metabolism is a difficult problem, it is not astonishing that we have not so far arrived at any conclusions which I would care to mention at this occasion.

Whatever their relation to chemical events, it is obvious that normally excitation is followed by a mechanical response. This can be measured either by recording the shortening or the development of tension in the muscle and we shall first follow the latter approach. When a muscle is stimulated isometrically and its tension is recorded by means of suitable gauges, it is seen, as is pictured in Figure 2, that upon a single stimulus the muscle develops tension and subsequently relaxes. If the stimulation is repeated at a suitable frequency, the muscle is kept in a constant state of activity and there results an isometric tetanus in which a higher degree of tension is maintained for as long as the stimulation is

applied. It might seem that such observations constitute a correct and fundamental description of the mechanical activity, but we owe to A. V. Hill and his school the important insight that we are dealing here only with the macroscopic manifestations of mechanical activity and that the fundamental events have quite a different course. This is likewise indicated in Figure 2 and can be described by saying that upon a single stimulus the muscle very rapidly achieves what is called the active state which it maintains at a full plateau of activity for a certain length of time and which thereupon declines. On tetanic stimulation, on the other hand, the active state is maintained for a long period and is then interrupted when stimulation ceases. Compared to these fundamental events, the macroscopically observable tension becomes manifest only with a certain delay, and we shall have to understand first what is the reason for this delay. In order to do so we shall first have to explain, making use of the lower sections of Figure 2, that the mechanically active parts of muscle consist of two elements in series; these are called the contractile elements and the series elastic elements. We have no information as to the morphological identity of those two structures, but their existence is established by various kinds of indirect experimentation. Only the contractile structure is activated by stimulation; it has the property of responding to stimulation by the almost instant development of tension and by a tendency to shorten, but this shortening, for molecular kinetic reasons which are not yet understood, proceeds according to a characteristic time course. Now when the muscle is studied under isometric conditions, it is clear that tension becomes recordable, not as soon as the contractile structures have developed it, but as soon as the series elastic components have been stretched to a sufficient extent that they too bear that same amount of tension. Since this stretching occurs by the shortening of the contractile components, it follows that the macroscopically observable tension does not appear instantly, but appears only to the extent that the contractile components shorten according to the time course previously alluded to. It is this interaction between the velocity relation of the contractile structure and the length-tension characteristics of the elastic structure which determines the measurable development of tension. The diagrams at the bottom of Figure 2 will illustrate this. At point 1 the contractile structure is inactive and both it and the series elasticity are at resting lengths; shortly after the stimulus, at time 2, the contractile structure is activated, but inasmuch as the series elasticity has not yet been stretched this does not immediately lead to manifest tension. Only later in the twitch, for example at point 3, has the contractile component shortened sufficiently to cause the amount of extension of the series elasticity required for the manifestation of tension. This would proceed further until the maximal tension in the contractile component became measurable were it not for the fact that at this time, for example at point 4, the active state has been terminated so that no further shortening of the contractile component takes place. From this moment on the tension will decrease again, and the result is that in the isometric twitch, because of the described delays, the maximum possible tension has never become observable. If stimulation is maintained by tetanic repetition, it is clear that eventually the total tension in the contractile structure shows itself so that the measurement of tetanic tension provides a measure and definition of the full intensity of the active state. In a single twitch, however, we will usually not reach this. It would carry us too far to give a complete description of all the experimental devices which may be used for detecting the active state during the course of the single twitch. It may suffice to state, qualitatively, that if right after the moment of stimulation we rapidly stretch the muscle over such a range that the series elastic component is lengthened by just the amount it has to be lengthened in order to support the maximum tension in the active state, we will reach the full intensity of the active state almost instantaneously and be able to observe its subsequent decline. This, and other ways of experimentation developed by Hill and his school, have led to a thoroughgoing description of the establishment,

intensity, and decay of the active state in response to a single stimulation.

With this knowledge, we can next turn to the problem of what physiological mechanisms might cause variations in the intensity of a twitch. Such variations, for example, might be brought about experimentally by suspending the muscle not in a normal Ringer solution, but in one in which all the chloride has been replaced by nitrate or iodide. It has been found, as was discovered by Kahn and Sandow [16], that in such a medium single twitches become much stronger. The subsequent analysis by Hill and Macpherson [9] has shown that this is due to a lengthening of the duration of the active state. It is obvious, by inspection of Figure 2, that if the duration of the active state were to be prolonged, more time would be given for the contractile component to shorten and so more tension will become observable by isometric measurements. Theoretically, it may even be possible to lengthen the active state to such an extent that the full intensity of it would become experimentally measurable, although so far this has not been realized. There is good reason to believe that several pharmacological reagents, as well as physiological regulators, may act on muscle by determining the duration of the active state which follows a single stimulus. It is important to emphasize that bathing in nitrate or iodide will cause this strengthening of contraction even when the time in the bath is just sufficient to allow the abnormal ions to diffuse into the extracellular spaces of the muscle, but definitely too short to permit any penetration of these ions into the interior of the cell. In other words, the ionic composition of the extracellular fluid, which is in contact with the cell membrane's exterior, determines the course of the activation events inside and this must mean that the condition of the membrane has a great influence upon the conduct of the events inside the cell.

Since we are still talking about the events which follow a single stimulus, it might be asked which attribute of the excitatory process is affected by the extracellular ions in such a fashion. The action potential itself does not show any changes, at most there is some modification of the after potential which is probably relevant, but which has not by itself led to a great amount of insight. Recently, there was published a fundamental paper by Bianchi and Shanes [2], in which it was shown that while a resting muscle exchanges a certain amount of calcium with its medium, this exchange of calcium is greatly increased during stimulation; furthermore, when stimulation is conducted in a nitrate medium, this calcium exchange is still further increased. Extrapolating from this important discovery, we may probably reason that the amount of calcium exchanging between the inside and the outside of the cell is an important attribute of the excitatory event and that the extent to which this occurs is a determining factor in deciding the duration of the active state which is elaborated within.

It may be argued that single twitches are of very limited physiological importance. I would like to answer this in two ways: on the one hand, it may be true that activity of skeletal muscle is usually in the nature of a tetanus; however, if it so happens that the study of single twitches opens up new insights into the mechanism of excitation-contraction coupling, we should fully explore these possibilities. Secondly, there are muscles which fundamentally contract in twitches and the most important of these is the heart. I would like, therefore, to discuss briefly one other important physiological question: what determines the strength of a cardiac contraction. I realize, of course, that to a large extent this is determined by various hemodynamic factors which may, in terms of Starling's law, be expressed by the common denominator of diastolic filling which in turn may be equated with initial fibril length. However, even when this parameter is kept constant there is, nevertheless, the possibility of significant physiological variations, not to mention the pathological modifications which are known as hypodynamicity or heart failure. For experimental purposes, variations in cardiac contractility can be brought about simply by changing the frequency of stimulation in the sense of the staircase effect. When within limits the frequency of stimulation is increased

the individual contractions become stronger. Such inotropic variations definitely correspond to effects which must occur in the body when the heart rate is changed, and furthermore, they may serve as an experimental device to study variations in contractile strength *per se*. Our experiments have shown that normally an increased strength of contraction is not caused by a lengthening of the active state, as might have been expected from an analogy with skeletal muscle, but that the duration of the active state is either not changed or is even shortened. What we did observe was that the higher tension is reached very rapidly. Descriptively, one may explain this by an increased velocity of contraction of the contractile component. Whether this is caused by enhancement of its fundamental force-velocity relation or whether it is caused by an increased intensity of the active state, is something we have not yet decided [1].

We may conclude from the foregoing that three different factors may determine the course and intensity of a single contraction in any type of muscle: the intensity of the active state, the duration of this state, and the velocity characteristics of the contractile component. All three of these are fundamentally variable and an important chapter of future physiology (and pharmacology and pathology, for that matter) will be devoted to the analysis of how different physiological regulations express themselves in terms of these three mechanisms. At the same time, another part of future physiology, or if you wish biophysics, will be devoted to the analysis of how the characteristics of the membrane leading into the excitatory events do by themselves determine these three main characteristics of the contractile phenomena. This is currently one of the main topics of investigation in my laboratory, but as yet we are still unable even to decide on the scope of the problems which are opened by this. Specifically for the heart, there seems to be a good relation between certain mechanical features and some of the phenomena studied electrophysiologically by means of intra- or extracellular electrodes. Dr. Brady [3] has begun to accumulate evidence that the duration of the active state correlates well with the duration of the plateau of the action potential. However, he has found no correlation whatsoever between either the intensity of the active state or the velocity characteristics of contractile components and any of the electrophysiologically demonstrable characteristics of the excitatory events. It might be, for example, that the amount of calcium exchange in a stimulus determines the duration of the active state, but that the intensity of the active state and the velocity characteristics of the contractile structure are determined by other means. Nevertheless, it is clear that these properties, too, are under constant control of membrane events.

We must leave the further discussion of these problems to the future and now turn to the question of how the fundamental activity of the contractile structure can be interpreted in biochemical and molecular terms. Evidence on this point is converging independently along two different biochemical lines of investigation. First, inasmuch as mechanical activity involves the mobilization and utilization of energy, there must be a connection between the contractile structures and the only source of energy to which biological systems seem to have access, namely, the chemical reactions of metabolism. Second, knowledge must be acquired as to the chemical identity of the contractile structure in its different morphological manifestations. Along the first line of investigation it has long been accepted that physiologically the energy for prolonged muscular activity is supplied by the oxidative reactions of respiration whereas for shorter periods of muscular activity the energy is provided by glycolysis. It has become clear over the years that these two gross over-all events of metabolism are quite remote from the fundamental reactions in contractile activity. For example, one can exclude oxygen completely and prevent the formation of lactic acids by suitable poisons and yet obtain perfectly normal contractions for some time. The most fundamental biochemical reaction in contractile activity so far identified is the splitting of adenosinetriphosphate (ATP) to adenosinediphosphate (ADP) and

phosphate which in activity of brief duration can be balanced by a concomitant splitting of creatine phosphate (CP) to creatine (C) and phosphate. The relation of gross metabolic events to these specific reactions is indirect inasmuch as both respiration and glycolysis seem to have the sole purpose of resynthesizing adenosinetriphosphate to the extent that it has been broken down in energy-requiring activities (Fig. 3).

Concerning the chemical identity of the contractile structures, we can best start with the statement that in the 1920's it was established that the bulk of the contractile structure can be identified with a single protein named myosin. Myosin has a number of unusual chemical and physical characteristics which can all be related to the fact that it consists of very long asymmetric molecules which make it eminently suitable as the building unit for a filamentous structure such as the muscle fibril. The prominent roles of myosin in muscle physiology became even more evident in 1939 when Engelhardt and Ljubimova [5] discovered that it has enzymatic properties since it acts as a catalyst causing the hydrolytic splitting of

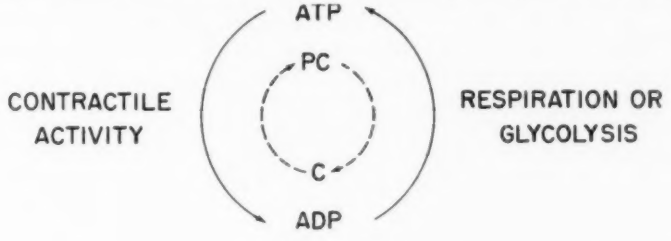


FIG. 3

A diagram of the relationship between muscular activity and metabolism. This scheme illustrates that activity is correlated with a breakdown of adenosinetriphosphate (*ATP*) to adenosinediphosphate (*ADP*), while a resynthesis of adenosinetriphosphate is caused by oxidative or glycolytic metabolism. Adenosinetriphosphate can also be resynthesized rapidly at the expense of phosphocreatine (*PC*) by breakdown of the latter substance to creatine (*C*). This coupling with the phosphocreatine cycle may constitute a reserve of adenosinetriphosphate for rapid mobilization, but may also have a more fundamental significance, not known as yet.

adenosinetriphosphate. In other words, myosin acts as an adenosinetriphosphatase. This relatively simple discovery opened momentous perspectives because it suddenly became clear that the major structural protein of the contractile filaments of muscle is also the catalyst which causes the energy-yielding reaction to proceed. The recognition of this intimate connection between structure and energy metabolism has probably been one of the greatest single events in contemporary physiology and biochemistry. Yet, by itself, it provided little demonstration of the actual relationship between the chemical and mechanical occurrences during contraction. The even more momentous discovery of this relationship took place in the early 1940's in the laboratory of Albert Szent-Györgyi [18,28] in Hungary. This observation took its starting point from the finding that myosin is not the only important structural protein in muscle, but that it occurs in association with another one which was called actin. These two proteins can combine to form a complex, actomyosin, which can be prepared from muscle and which in its physical properties shows some remarkable responses in the presence of adenosinetriphosphate. The most striking observation in this regard was made by spinning actomyosin gels into tiny threads. When placed in a suitable medium, containing notably potassium and magnesium salts, these threads were shown to contract vigorously following the addition of adenosinetriphosphate. The contraction of these actomyosin threads has many imperfections when compared with the activities of the living organ, but the remarkable part is not how imperfect the demonstration is, but the fact that it can be made at all. Certainly, this is an indication that in the actomyosin structure, physical reactions are possible which may well constitute the whole of the contractile activity when they occur in the organized

manner possible only in the living cell. In fact, a far more perfect *in vitro* experiment was also designed by Szent-Györgyi. After extracting almost everything from a strip of muscle fibers by means of aqueous glycerol, leaving the actomyosin structure in its original configuration, these glycerol-extracted muscle fibers can be made to contract by the addition of adenosinetriphosphate. They shorten and lift weights very much as muscles can do. These actually develop about the same tension as the muscles from which they are derived. All such observations give us some indication of the potentialities inherent in the myosin and actin structures and emphasize the need to know more about the chemical and molecular properties of these two structural proteins.

In the 1940's and 1950's a great deal of attention was given to the chemistry of myosin and actin, both of which were obtained in the purified form necessary for a study of their physical-chemical properties. Let us briefly summarize the results of these inquiries.

With respect to myosin we must first mention the extensive physical studies by such techniques as ultracentrifugation, light-scattering, viscosity, and flow birefringence. These studies have all indicated that the myosin molecule is greatly elongated. It may well have the shape of a rod which is about 1600 Ångström units long with a molecular weight of 420,000, corresponding to a thickness of about 20 Ångström units. Its structure may be regarded as a helix composed of three protein chains [19,20,21,23].

Actin, by contrast, can occur as a single globular molecule, named G-actin, which has a molecular weight of 58,000, corresponding to a dimension of the order of 40 or 50 Ångström units. In the presence of salt, these single globular molecules tend to unite in chains to form F-actin, which is a polymer of G-actin. F-actin forms long molecular strands which may be just the thickness of a single strand of molecules but which may assume any length.

Both myosin and actin have interesting relationships to adenosinetriphosphate. As I mentioned before, myosin is an adenosinetriphosphatase and the study of this enzymatic property has led to a wealth of information which is so staggering and confusing that we hardly know what to do with it. If I may single out one of our results, I should allude to recent findings [25] that in interacting with adenosinetriphosphate, one myosin molecule displays one binding site with which one adenosinetriphosphate molecule apparently combines with great affinity. The relationships between actin and adenosinetriphosphate are different. Adenosinetriphosphate is necessary to keep globular actin in an undenatured form. During the polymerization process one adenosinetriphosphate molecule is broken down to adenosinediphosphate and phosphate for every G-actin molecule which enters into the polymer structure. It can be calculated that if this polymerization were to occur once in a single muscle twitch, the reaction might well account for the total observed energy consumption. However, there is no direct information whether or not the transformation of G- to F- actin actually does occur in living muscle during activity. In broad terms, however, it is obvious that both actin and myosin have properties which make them eminently suitable to be the building stones of the contractile apparatus and of interacting with energy-yielding metabolic reactions in such a way as to make the energy transfer understandable. The actual mechanisms by which these effects occur remain to be investigated.

A great deal of progress has been made recently in the description of the submicroscopic structures of muscle including the location of myosin and actin in these structures. Classically, this problem has been investigated by means of polarization microscopy. Of necessity, this approach was indirect with limited potentialities, but it has nevertheless led to certain important insights. From the observation that the A-band of the sarcomere is birefringent in the polarization microscope and from quantitative measurements on the characteristics of this birefringence, it was concluded early that the A-band must consist of parallel

rods the dimensions of which could not be estimated, except to conclude that they were much thinner than could be discerned by optical microscopy. The nature of the structure of the I-band was less obvious, but the possibility could not be excluded that a certain amount of parallel orientation might occur here as well. Enormous advances in this field have recently been made by means of electron microscopy, beginning with the pioneer investigations in the laboratories of Schmitt, of Szent Györgyi and Wyckoff, of Draper and Hodge, and others, and currently culminating in the technically highly perfected investigations of Huxley and Hansen [14,15] and of Sjöstrand [26]. Although opinions are not unanimous in all respects, a certain general picture nevertheless arises which I may expect will undergo relatively little modification in the course of further work (Fig. 4).

The main result of these investigations has been the demonstration that, indeed, the entire sarcomere consists of an array of longitudinally oriented filaments of various thicknesses and sizes. Along the full length of the A-bands there is an

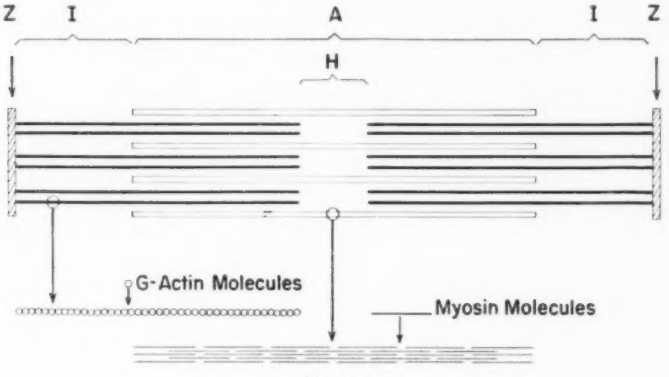


FIG. 4

Schematic diagram of the submicroscopic structure of a sarcomere of a single muscle fiber (AO- and I-bands, and other structures) based primarily on the electron-microscopic work of Huxley in conjunction with the molecular studies of the author. The scheme refers to one fibril from one Z-membrane to the next. The thin rods stretching from the Z-line through the I-band and into the A-band short of the H-zone are actin filaments; the heavy rods making up the full length of the A-band are myosin particles. The relationships of these two types of rods to their molecular constituents are tentatively indicated in the lower part of the diagram.

assembly of relatively heavy rods, which are as long as the A-band is long and are of the order of 100 to 150 Ångström units thick. By means of selective extraction techniques, Hansen and Huxley could demonstrate that these rods consist of myosin. Inasmuch as they are much longer and thicker than myosin molecules which occur in solution, it is obvious that they do not consist of single myosin molecules. On the contrary, they must consist of assemblies of these molecules in a very regular arrangement and shape which can, perhaps, be looked upon as submicroscopic crystals. Thinner filaments run from the Z-line across the entire lengths of the I-band, well into the A-band; they cease in the middle of the A-band so that a central portion of the latter, called the H-zone, contains myosin rods, but does not contain the other thinner rods. The thin rods have been identified by Hansen and Huxley as consisting of actin. Both the actin and the myosin rods are arranged in highly regular manners so that in cross section they reveal a regular pattern in hexagonal arrangements. Hansen and Huxley further believe that in contraction or in stretching, the length of the A-bands and consequently that of the myosin rods does not alter but that contraction or stretch consists in a sliding of actin filaments into or out of the space occupied by myosin. This conclusion is in good agreement with what may be deduced from observations with the interference microscope, or by means of phase-contrast microscopy. From here on, how-

ever, opinions begin to differ and we must leave it to the future investigations of these authors to determine whether the myosin rods really remain unaltered in lengths under all circumstances or whether other modifications of the current picture become necessary. It has also been demonstrated that between the myosin rods and the actin rods there exist bridges which may well play a role in the mechanism by which sliding or deformation will occur.

Other efforts of great interest are being made by Holtzer and Marshall by means of fluorescent antibodies [13]. Specific antibodies against myosin and actin are prepared by the usual techniques and are subsequently labeled by means of fluorescent dyes chemically attached to them. When such fluorescent antibodies are then applied to isolated myofibrils they will attach themselves onto the structures against which they are directed, so that subsequent observation in the fluorescence microscope will allow conclusions as to the localization of myosin and actin within the sarcomere. In very gross terms, such observations have confirmed the occurrence of myosin in the A-band, and of actin in the I-band and part of the A-bands. In detail, there are some important discrepancies which will need explanation by future work. One has not, so far, been able to associate the contractile and the series elastic components with definite morphological structures.

So far, the tenor of my discussions has been entirely optimistic; I should not fail to mention, however, that certain more disturbing situations also exist in this field. In general terms, one could be somewhat uneasy about the fact that many parts of the tentative picture have been based on the indirect forms of experimentation. For example, the usual assumption that muscle contraction is primarily a breakdown of adenosinetriphosphate had never been tested by direct experiments on isolated muscles; the formidable technical difficulties seemed to discourage such an attempt.

When it was finally undertaken, some rather large surprises revealed themselves. Let me take a few moments to discuss the experimental approach in this field because of the crucial significance of these problems. In order to demonstrate whether adenosinetriphosphate is broken down in a single twitch, an experiment would have to be designed in which the metabolism of two exactly comparable muscles, one unstimulated, the other stimulated, could be stopped simultaneously and instantaneously at the moment of contraction desired by the experimentor. Such instantaneous interruption is possible if the muscles are submerged with very great speed into a medium of low temperature and significant heat conduction and heat capacity. We have accomplished this by submerging the muscles in isopentane or liquid propane cooled in liquid nitrogen. Experiments of this nature have been performed during the last few years and to everyone's surprise they failed to demonstrate the breakdown of either adenosinetriphosphate or phosphocreatine under circumstances in which, according to the classic theory, this would definitely be expected [22]. I must make it clear, however, that this negative result does not at all definitely eliminate the type of biochemical explanation I have assumed during this discussion. Further work will be necessary to determine whether or not muscle contains other phosphorus-containing compounds which act in the same manner as phosphocreatine and conceal a primary breakdown of adenosinetriphosphate. Until this has been determined not much discussion is possible. If it should turn out that no primary breakdown of adenosinetriphosphate occurs, then we will have to face the issues squarely, but it is still to be expected that even in that case essential parts of the now-accepted picture will be maintained, and that our modification may only mean that although physiologically adenosinetriphosphate is the first definite chemical compound which can be associated with mechanical activity, nevertheless a certain amount of such activity is possible within the protein structures of the contractile compound before invoking the breakdown of adenosinetriphosphate. This might become a most fundamental modification of our current views, but it would not in any way diminish the important experimental evidence which led originally to the adenosinetriphosphate theory. More pro-

longed activity of muscle, however, is always accompanied by a breakdown of high-energy phosphate compounds. One can study such processes without the complications of high-energy phosphate synthesis by eliminating all other metabolic reactions by means of iodoacetate and anaerobiosis. This experimental approach is being used by us now, and also by Carlson at Johns Hopkins University in order to study quantitatively the relation between high-energy phosphate breakdown and the different aspects of mechanical activity [4,24]. Owing to the fundamental investigations of A. V. Hill, by means of heat measurements it is known that during activity muscle seems to mobilize energy in three different forms. These include the activation energy, which is mobilized in order to activate the contractile structure; the shortening energy which is proportional to the amount of shortening actually occurring; and thirdly, the energy which is involved in the performance of work. It might be thought, beforehand, that these three different forms of energy might originate in three different chemical reactions, each of these being called on separately according to the requirements. Our results, however, indicate that this is not the case, but rather that all three forms of energy result from the same process which, under the conditions of our experiments, manifests itself predominantly as a breakdown of phosphocreatine. Some of this chemical change corresponds to the activation energy, some to the shortening energy, and some to the work performed. On the surface this might appear to be not unexpected, since it was obvious that the three forms of energy discovered by Hill must have some biochemical counterparts. Nevertheless, it is clear that only by actual investigation of these interrelations will one eventually gain an insight into the nature of the mechanochemical coupling processes which constitute the muscle activity.

I might add that our rapid freezing technique is also being used for the investigation of other fundamental questions. For example, the electron microscopic study of the contraction process was carried out mostly on model experiments. We hope to be able, by means of the rapid freezing technique, in cooperation with Dr. Sjöstrand, to find a direct approach to the electron microscopy of the contraction of living muscle. Likewise, we hope to design experiments to determine what chemical or physical transformations are being carried out by myosin and actin in the course of the contraction process.

In reviewing the different sections of this essay, one will end with the mixed feeling that, on the one hand the study of muscle function has consistently been in the forefront of the advance in the biological sciences, but that, nevertheless, nothing is really explained in a final form. As biologists, we have learned to live with a degree of ignorance which would be unacceptable in other sciences, but which to us has become a mode of life directly reflecting the profound complexity of living matter and its activities.

## REFERENCES


1. Abbott, B. C., and Mommaerts, W. F. H. M.: A Study of Inotropic Mechanisms in the Papillary Muscle Preparation. J. Gen. Physiol., **42**: 533-551, 1959.
2. Bianchi, C. P., and Shanes, A. M.: Calcium Influx in Skeletal Muscle at Rest, During Activity, and During Potassium Contracture. J. Gen. Physiol., **42**: 803-815, 1959.
3. Brady, A. J.: Unpublished work, 1959.
4. Carlson, F. D.: Unpublished work, 1959.
5. Engelhardt, W. A., and Ljubimova, M. N.: Myosine and Adenosinetriphosphatase. Nature, **144**: 668-669, 1939.
6. Hill, A. V.: Muscular Activity. Baltimore, The Williams and Wilkins Co., 1925.
7. Hill, A. V.: The Priority of the Heat Production in a Muscle Twitch. Proc. Royal Soc., London, Ser. B, **148**: 397-402, 1958.
8. Hill, A. V., and Howarth, J. V.: The Effect of Potassium on the Resting Metabolism of the Frog's Sartorius. Proc. Roy. Soc., London, Ser. B, **147**: 21-43, 1957.
9. Hill, A. V., and Macpherson, L.: The Effect of Nitrate, Iodide and Bromide on the Duration of the Active State in Skeletal Muscle. Proc. Royal Soc., London, Ser. B., **143**: 81-102, 1954.
10. Hodgkin, A. L.: The Ionic Bases of Electrical Activity in Nerve and Muscle. Biol. Rev., **26**: 339-409, 1951.
11. Hodgkin, A. L.: Ionic Movements and Electrical Activity in Giant Nerve Fibres. Proc. Royal Soc., London, Ser. B, **148**: 1-37, 1958.

12. Hodgkin, A. L., and Horowicz, P.: Effects of K and Cl on the Membrane Potential of Isolated Muscle Fibres. J. Physiol., **137**: 30P., 1957.
13. Holtzer, H.; Marshall, J. M., Jr.; and Finck, H.: An Analysis of Myogenesis by the Use of Fluorescent Antimyosin. J. Biophys. Cytol., **3**: 705-724, 1957.
14. Huxley, H. E.: The Double Array of Filaments in Cross-Striated Muscle. J. Biophys. Cytol., **3**: 631-648, 1957.
15. Huxley, H. E., and Hansen, J.: Changes in the Cross-Striations of Muscle During Contractural Interference Microscopy of Living Muscle Fibres. Nature, **173**: 971-973, 1954.
16. Kahn, A. J., and Sandow, A.: Potentiation of Muscular Contraction by Nitrate-Ion. Science, **112**: 647-649, 1950.
17. Ling, G. H.: *In* Phosphorus Metabolism: A Symposium on the Role of Phosphorus in the Metabolism of Plants and Animals, p. 748. Edited by W. D. McElroy and H. B. Glass. Baltimore, Johns Hopkins Press, 1952.
18. Mommaerts, W. F. H. M.: Muscular Contraction: A Topic in Molecular Physiology. New York, Interscience Publishers Inc., 1950.
19. Mommaerts, W. F. H. M.: The Molecular Transformation of Actin. I.Globular Actin. J. Biol. Chem., **198**: 445-457, 1952.
20. Mommaerts, W. F. H. M.: The Molecular Transformations of Actin. II.The Polymerization Process. J. Biol. Chem., **198**: 459-467, 1952.
21. Mommaerts, W. F. H. M.: The Molecular Transformations of Actin. III.The Participation of Nucleotides. J. Biol. Chem., **198**: 469-475, 1952.
22. Mommaerts, W. F. H. M.: Investigation of the Presumed Breakdown of Adenosine-Triphosphate and Phosphocreatine During a Single Muscle Twitch. Am. J. Physiol., **182**: 585-593, 1955.
23. Mommaerts, W. F. H. M., and Aldrich, B. B.: Determination of the Molecular Weight of Myosin; Interference—Optical Measurements During the Approach to Ultracentrifugal Sedimentation and Diffusion Equilibrium. Biochem. Biophys. Acta, **28**: 627-636, 1958.
24. Mommaerts, W. F. H. M., and Seraydarian, K.: Unpublished work, 1959.
25. Nanninga, L. B., and Mommaerts, W. F. H. M.: The Binding of Adenosinetriphosphate by Myosin. Federation Proc., **18**: 292, 1959.
26. Sjöstrand, F. S.; Andersson-Cedergren, E.; and Dewey, M. M.: The Ultrastructure of the Intercalated Discs of Frog, Mouse and Guinea Pig Cardiac Muscle. J. Ultrastruct. Res., **1**: 271-287, 1958.
27. Szent-Györgyi, Albert: Chemistry of Muscular Contraction. Ed. 2. New York, Academic Press Inc., 1951.
28. Szent-Györgyi, Albert: Chemical Physiology of Contraction in Body and Heart Muscle. New York, Academic Press Inc., 1953.

# Transitory Demineralization of the Hip in Pregnancy

## A Report of Three Cases

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Aches and pains in various portions of the body are common complaints of the pregnant woman, and complaints of "hip pain" are comparatively frequent. To the best of our knowledge, however, changes seen roentgenographically in association with hip pain in pregnancy have not been previously described. Two such cases have been personally seen by one of us (P.H.C.), and the third was brought to our attention by a colleague.

Case 1. H. S., a woman, twenty-eight years old, was first seen in the eighth month of her fourth pregnancy in September 1956 with a history of pain of six weeks' duration in both hips and thighs when walking. She had been treated by her local physician by "deep heat and muscle relaxants" without relief, and had spent the previous three weeks in bed. Her past medical history was non-contributory except that she had not had back or hip pain with three prior, uneventful pregnancies and deliveries. On physical examination, the patient had little pain when quiet, but could not be moved from her bed because of severe pain in both hip areas on motion. Neurological evaluation showed no reflex or sensory changes, or definite muscle weakness in either lower extremity, although testing of the hip abductors and adductors caused slight increase of pain. With the knees flexed to 90 degrees, the patient was able to flex both hips actively to 90 degrees, but in this position both hips were held in 30 degrees of external rotation and could not be passively rotated to neutral without causing severe hip pain. Straight-leg raising was possible to only 45 degrees bilaterally accompanied by severe pain in the hip, but no discomfort in the back or pain in the sciatic distribution. There was no local tenderness, heat, or swelling about the hips, and no palpable inguinal lymph nodes. Laboratory examinations showed no abnormalities in the routine urinalysis. The fasting blood sugar was 103 milliliters per 100 cubic centimeters. The total protein was 6.6 milliliters per 100 cubic centimeters, with an albumin-globulin ratio of 6.8 to 4.1. The hemoglobin was 12.5 grams and the red-cell count was 4,100,000 with a hematocrit of 4 per cent. The white-cell count was 9,500 with a normal differential. The sedimentation rate was 34 milliliters per hour, corrected. The serum calcium was 9.8 milliliters per 100 cubic centimeters, serum phosphorus was 4 milliliters per 100 cubic centimeters, and alkaline phosphatase was 8.5 Shinowara* units. A lumbar puncture was done; this showed a normal pressure and clear cerebrospinal fluid with a protein content of 8 milliliters per 100 cubic centimeters. Anteroposterior and lateral roentgenograms of the chest and the lumbar spine showed no abnormalities. A roentgenographic study of the hips and pelvis, however, showed marked demineralization of both femoral heads and acetabulae (Fig. 1-A). The patient remained unchanged clinically, and on September 19, 1956, she was discharged, without a definite diagnosis, to her home in another state under the care of her family physician. In October 1956 she delivered a normal male infant, without difficulty. The patient shortly afterward stated that right after delivery the hip pain had abated rather rapidly, and three weeks later the right lower extremity was "about back to normal", although she still had some discomfort in the left hip. By January 1, 1956, two and a half months after delivery, the patient was well enough to walk on high heels and even jitterbug a little. Nothing more was heard from the patient until February 1958 when the similarity of her case to that of the patient in Case 2 was recalled. At that time, she stated "I get around as well as ever". Roentgenograms made shortly after delivery in October 1956 were requested and obtained, as well as new roentgenograms made on February 27, 1958 (Fig. 1-B). Both sets of roentgenograms disclosed an impacted subcapital fracture of the left femur, which had healed without treatment or the patient's knowledge of its presence.

* The Shinowara method is a modification of the older Bodansky method of determination of alkaline phosphatase and is about 80 per cent more sensitive. A Shinowara unit equals 1.8 × a Bodansky unit. The normal range by the Shinowara method is 4 to 8 units in adults and 5 to 20 units in children.

FIG. 1-A

Case 1. September 13, 1956, initial roentgenogram made six weeks after onset of symptoms. Note spotty demineralization, most marked on right, of both femoral heads and acetabulae.

FIG. 1-B

February 27, 1958, sixteen months after delivery. There is normal mineralization bilaterally. The left subcapital fracture has healed with re-establishment of the normal trabecular pattern, but moderate varus deformity.

FIG. 2-A

Case 2. December 23, 1957, five days after delivery. There is demineralization of the spotty type involving the femoral head and acetabulum on the left. The right hip is normal.

FIG. 2-B

February 26, 1958, nine weeks after delivery. There is normal roentgenographic appearance bilaterally.

CASE 2. N. H., a woman, twenty-eight years old, was first seen in November 1957 in the ninth month of her second pregnancy. She complained of a "dull and toothachey" pain of one month's duration in the front of the left hip and thigh. This pain had been gradual at onset and although, at first, helped by rest became almost constant, spreading down the back and side of the left lower extremity as far as the ankle. The past medical history was non-contributory, and she had had no difficulty with her previous, uneventful pregnancy. Physical examination showed no reflex, sensory, or motor changes in either lower extremity and a normal painless range of motion of the left hip. There was slight tenderness in the trochanteric and gluteal areas of the left hip as compared with the right. Routine urinalysis showed no abnormalities. The hemoglobin was 12.3 grams and the white-cell count was 5,900 with a normal differential. The sedimentation rate was 47 millimeters per hour. The serum calcium was 9.2 milliliters per 100 cubic centimeters, serum phosphorus was 3.7 milliliters per 100 cubic centimeters, and alkaline phosphatase was 9.5 Shinowara units. Roentgenograms of the left hip made after delivery on December 18, 1957, showed localized demineralization of the left femoral head and acetabulum (Fig. 2-A). The patient's complaints remained essentially unchanged for approximately three weeks after delivery, at which time there began a gradual diminution of symptoms. On re-examination on February 26, 1958, the patient stated that she was completely free of any pain and thought that the hip was normal. Subsequent follow-up by clinical examination showed that the patient had remained free of symptoms, and the roentgenographic examination showed that the left hip had returned to normal (Fig. 2-B).

CASE 3. R. B., a woman, thirty-five years old, was first seen three months after the uneventful delivery of her third child. Four weeks prior to this delivery a steady aching pain had gradually developed in the lateral aspect of the left hip. The pain radiated to the anterior and lateral aspects of the thigh, was worse on activity, and was helped only slightly by rest. At the first examination, the patient walked with a marked limp on the left side and was using crutches. There was slight localized tenderness over the anterior and posterior aspects of the left hip, but no swelling or increased warmth. There was a full range of motion of the left hip, as compared with the right, but all motions, especially abduction and internal rotation, were painful at the extreme limit of range. There were no motor, sensory, or reflex changes in the lower extremity. Roentgenograms made at this time (September 1953) showed demineralization of the left femoral head—roentgenograms strikingly similar to those of the other two patients (Fig. 3-A). When the patient was re-examined (October 1953) there was slightly less pain, but she still walked with a cane. Examination showed a normal range of painless flexion and extension of the left hip, but still slight pain at the extremes of rotation and abduction. This patient subsequently moved from Cleveland and was not seen again until January 1958, when we requested that arrangements be made for obtaining roentgenograms of her hips (Fig. 3-B). The patient told us that her symptoms had not subsided to an appreciable degree until seven to nine weeks after delivery, and she was not entirely free of pain until approximately six months after delivery. After that time she had only a rare, momentary twinge of pain in front of her left hip.

## DISCUSSION

We do not know the etiology of this syndrome. There is no laboratory or clinical evidence to support a diagnosis of infection. A tentative diagnosis of rheumatoid arthritis had been made in the first patient (H. S.) at the time of discharge from the hospital, but there was nothing after a follow-up period of three years to support that diagnosis. In none of the three patients did further joint symptoms at all suggestive of rheumatoid arthritis develop. The elevated sedimentation rate shown in each patient is a constant accompaniment of an uncomplicated pregnancy. We cannot conceive of a metabolic disturbance, such as osteomalacia of pregnancy, that would selectively act on the hip joint alone, without generalized skeletal manifestations, either on roentgenograms or by laboratory evidence. We considered the possibility of a selective and painless demineralization of the femoral head occurring as a hitherto unrecognized finding in pregnant women and therefore reviewed 100 unselected pelvimetry roentgenograms that showed both hips; none disclosed any evidence of demineralization of the femoral head. An interesting roentgenographic finding in all three patients was the presence of spina bifida occulta involving the first sacral segment. There is no reason to suspect, however, that this finding is anything other than coincidental.

We believe that the close connection between the site of changes as seen by

FIG. 3-A

Case 3. September 26, 1953, sixteen days after delivery. There is demineralization of the left femoral head and acetabulum, but the right femoral head is normal.

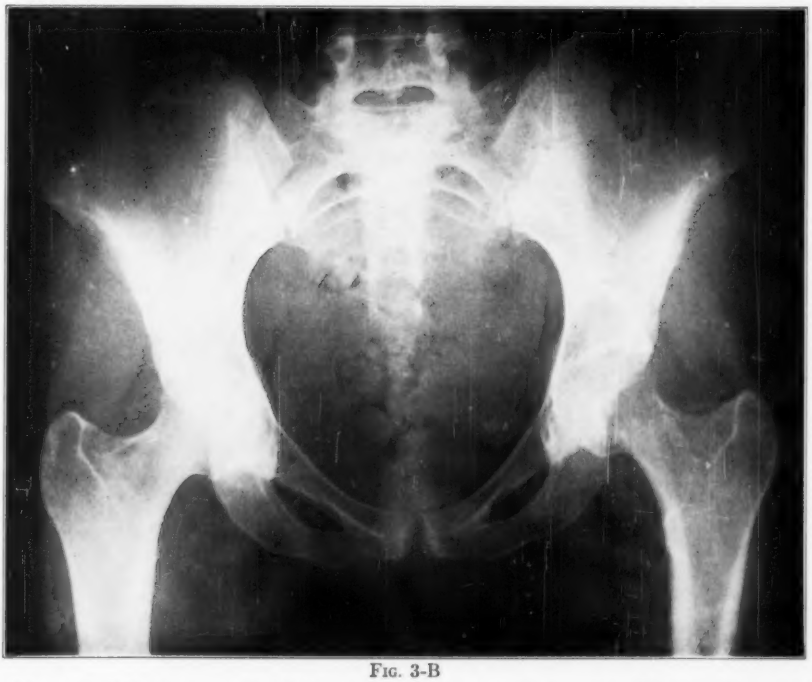

FIG. 3-B

March 16, 1958, five years after delivery. There is remineralization of the left hip with normal bone architecture, and no evidence of narrowing of the joint space or of arthritic change.

roentgenogram and the complaints of pain indicate a selective and localized demineralization. There is no doubt, however, that a skeletal survey would be of value to confirm this connection, although such a survey would have to wait until after delivery. If feasible, a skeletal survey will be made of subsequent patients with this entity.

A selective local demineralization such as this, accompanied by pain, most strongly suggests a neurogenic origin, such as seen in causalgia or Sudeck's atrophy. Bone atrophy after nerve section has been attributed by some observers as due only to the disuse of the paralyzed limb, rather than an actual effect of the interruption of the nerve supply to bone [1]. Many of the fibers going to a joint are vasomotor, supplying the blood vessels in the capsule and synovial tissue, thereby controlling blood flow through the joint [3]. But sympathectomy, as has been done for leg-length discrepancy, with presumed resulting increase in local blood supply does not appreciably affect the degree of bone atrophy seen in a paralyzed limb. Section of the obturator nerve, the major sensory innervation of the hip joint, has never been shown to lead to localized demineralization of the femoral head. The effect of intermittent partial pressure of the child's head against the obturator nerve in its course across the brim of the true pelvis has, however, been considered. This mechanism, occurring on engagement of the child's head in the pelvic inlet, is anatomically feasible. Compression on the lumbosacral cord as it crosses the pelvic brim, resulting in peroneal palsy was described by Brown and McDougall as the cause of "traumatic maternal birth palsy". Roberts, a veterinary surgeon, described obturator paralysis in cattle due to the bone tuberosities of the fetal hips, especially the greater trochanters, rubbing on the obturator nerve. This results, however, in a definite paralysis of the adductors; there is usually recovery within two to seven days after delivery. No known roentgenographic studies of the hip joints of cattle with this condition have been made.

In the three patients just described, however, no definite motor weakness, particularly of the hip adductors, could be identified.

The effect of section and compression of the obturator nerve was investigated by means of a simple experiment. Five female dogs were operated on while under pentothal anesthesia, and through a low abdominal mid-line incision the obturator nerves were identified at the point at which they crossed the brim of the pelvis. The left nerve was sectioned at this point, and the right was gently compressed with a silver neurological clip. Preoperative roentgenograms were made, after which an anteroposterior roentgenogram of the pelvis and both hips was made of each dog, at weekly intervals for a period of eight weeks. No demonstrable demineralization was noted. The possibility remains, however, that the clip caused physiological section of the nerve, rather than partial compression as was intended. Further experiments are planned to attempt to produce partial compression and irritation, rather than section.

## SUMMARY

Three cases have been presented of a syndrome occurring in pregnant women. This syndrome is characterized by pain of varying severity in one or both hips or thighs and develops in the last trimester of pregnancy. Roentgenograms show a spotty demineralization with sharply localized margins, involving one or both femoral heads, a small part of the femoral neck, and the acetabulum. In each of the three patients, the pain subsided and the roentgenographic appearance returned to normal within several months after delivery.

We do not know the cause of this syndrome, but suspect it to be of neurogenic origin.

NOTE: The authors would be pleased to learn of additional similar cases in the reader's experience, and would welcome suggestions as to etiology.

REFERENCES

1. Bell, G. H.: Bone as a Mechanical Engineering Problem. *In* The Biochemistry and Physiology of Bone. Edited by Goeffrey H. Bourne. Ch. 2, Sect. 7, pp. 45-49. New York, Academic Press Inc., 1956.
2. Brown, J. T., and McDougall, A.: Traumatic Maternal Birth Palsy. J. Obstet. and Gynaec. British Empire, **64**: 431-435, 1957.
3. Gardner, Ernest: Nerve Supply of Joints. *In* Instructional Course Lectures, The American Academy of Orthopaedic Surgeons, 1952. Vol. 9, pp. 155-161. Ann Arbor, J. W. Edwards, 1952.
4. Roberts, D. J.: Veterinary Obstetrics and Genital Disease. Ann Arbor, Edward Bros. Inc., 1956.

# Fracture of the Supracondyloid Process

## A Case Report

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The supracondyloid process is a small hook-shaped exostosis projecting from the anteromedial surface of the humerus five to seven centimeters above the medial epicondyle and varying in length from two to twenty millimeters. It curves forward and distally, its apex being connected to the medial epicondyle by a fibrous band. Through the tunnel thus formed pass the median nerve and the brachial artery, or one of its branches in case of a high bifurcation. The fibrous

Fig. 1

Anteroposterior and lateral roentgenograms of the left humerus made September 27, 1956, showing the large supracondylar process.

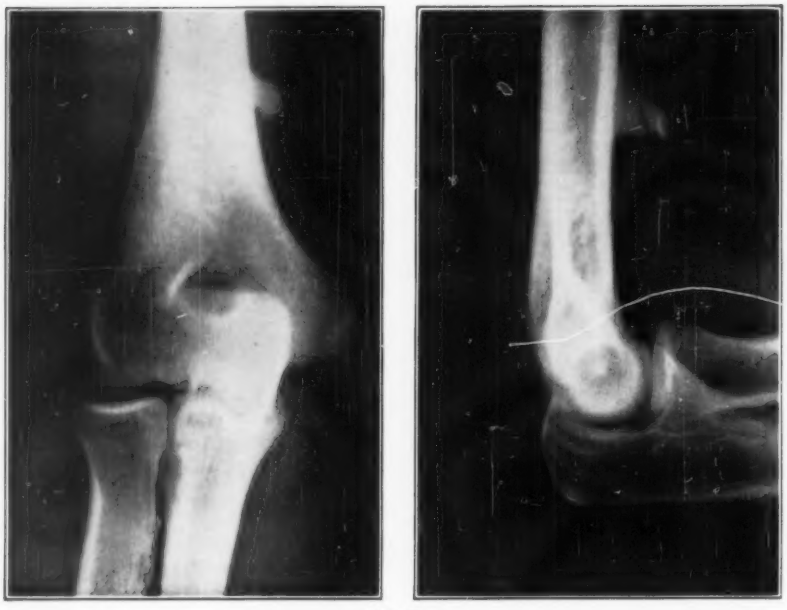

FIG. 2

Anteroposterior and lateral roentgenograms of the left humerus made October 17, 1956, showing fracture of the supracondylar process.

band usually gives origin to a portion of the pronator teres muscle. The supracondyloid process is a vestigial counterpart of a bone canal present in many reptiles and mammals; it occurs in approximately 1 per cent of people of European ancestry [2,4,8].

Anthropologists have been primarily interested in this entity because of its apparent link to the origins of the human races. Clinically, it is of interest to the orthopaedist because of possible compression of the median nerve.

Marquis and associates presented a review of the literature and reported three asymptomatic cases. Amos, in a communication to Parkinson, reported operative intervention with excision of the supracondyloid process in three symptomatic cases, in one of which there had been traumatic fracture of the process. In Europe, Mandruzzato reported five cases, in one of which surgery was required because of an old fracture of the process. As far as can be ascertained, Ganz published the only roentgenogram of a fracture of this outgrowth.

The present case is unique in that roentgenograms were obtained both before and after fracture of the process.

P.B., a seventeen-year-old white airman in basic training, was first seen September 27, 1956, in the Orthopaedic Clinic at Lackland Air Force Base, Texas. He complained of a bone projection over the distal anteromedial aspect of his left humerus. He stated that this had been noticeable for approximately two years and had been gradually enlarging. The only symptom was slight pain when the projection was bumped or pressed firmly. Roentgenograms revealed a fairly large supracondyloid process of the left humerus (Fig. 1).

On October 17, three weeks later, he was struck in the arm by a bottle. He was seen again at this time, complaining of increased local pain and tenderness with some radiation of pain down his arm into the index and middle fingers. There was no motor disturbance, but slight hyperesthesia was present in the involved fingers. Roentgenographic re-examination showed a fracture of the process (Fig. 2). The patient was admitted to the hospital, and on October 24, 1956, surgical excision of the supracondyloid process was performed, with wide resection of the periosteum around the base of the process, as recommended by Mandruzzato. The fibrous band was present, and through the foramen passed the median nerve and the brachial artery.

The pronator teres had the anomalous origin from the fibrous band just mentioned. The patient's symptoms were relieved after surgery, and he returned to full duty November 6, 1956.

## DISCUSSION

Although the supracondyloid process of the humerus is a relatively rare entity, the orthopaedist should be aware not only of its presence but also of its propensity to cause symptoms by compression of the median nerve. It should be ruled out in any patient with a so-called carpal-tunnel syndrome of an obscure nature. Palpation of the lower end of the humerus and increased pain with pronation of the extended forearm should suggest the diagnosis. Roentgenograms are confirmatory; however, to demonstrate smaller processes, oblique roentgenograms of the humerus may be necessary. In symptomatic cases, surgical excision of the process is the treatment of choice.

## REFERENCES

1. Amos, N. H.: Cited by Parkinson.
2. Barnard, L. B., and McCoy, S. M.: The Supracondyloid Process of the Humerus. J. Bone and Joint Surg., **28:** 845-850, Oct. 1946.
3. Ganz, E.: Fraktur des Processus supracondylicus humeri. Röntgen-Praxis, **9:** 48, 1937.
4. Gray, Henry: Anatomy of the Human Body. Ed. 25, p. 189. Edited by Charles Mayo Goss. Philadelphia, Lea and Febiger, 1948.
5. Mandruzzato, Francesco: Patologia e chirurgia del processo sopraepitrocleare dell'omero. Chir. d. Org. di Movimento, **24:** 123-132, 1938.
6. Marquis, J. W.; Bruwer, A. J.; and Keith, H. M.: Supracondyloid Process of the Humerus. Proc. Staff Meet. Mayo Clin., **32:** 691-697, 1957.
7. Parkinson, C. E.: The Supracondyloid Process. Radiology, **62:** 556-558, 1954.
8. Terry, R. J.: On the Racial Distribution of the Supracondyloid Variation. Am. J. Phys. Anthropol., **14:** 459-462, 1930.

# Osteochondrosis of the Upper Femoral Epiphysis Following Traumatic Dislocation of the Hip Joint

### Report of a Case

BY DR. A. CROS JUAN, CASTELLÓN DE LA PLANA, SPAIN

Traumatic dislocation of the hip is rare in children. Mason's review of the literature from 1922 to 1954 listed only eighty-eight such cases. In the series reported by Stewart and Milford of 193 dislocations of the hip, only seven occurred in children.

An intimate correlation exists between the extent of the injury and the concomitant damage to the blood supply of the femoral head. As Banks pointed out, avascular necrosis of the femoral head may follow the injury as a not infrequent complication. Because of the rarity of this injury and its interesting complications, the present report of a case is submitted.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Roentgenogram showing posterior dislocation of the left hip.
Fig. 1-B: Full reduction of the dislocation.

FIG. 1-C

Roentgenogram made fifteen months after injury.

J. M. S., a boy, eight years old, was struck by a car while riding his bicycle. He was thrown to the ground, landing on his left knee. Three days later, because of persistent flexion and adduction of his left hip, he was referred to us. Roentgenograms (Fig. 1-A) showed a posterior dislocation of the left hip joint. With the patient under general anesthesia, the dislocation was reduced by traction in the long axis of the femur with the hip flexed to 90 degrees. A below-the-knee plaster spica was applied with the affected hip in moderate abduction. Roentgenograms a few days later (Fig. 1-B) showed satisfactory reduction. The cast was removed after ten weeks, and motion was begun and continued for four weeks without weight-bearing. Normal weight-bearing was permitted fourteen weeks after the reduction. Fifteen months after injury the hip was normal to clinical examination except for slight limitation of internal rotation which, at the time of writing, still persists. A roentgenogram (Fig. 1-C) at this time showed that the upper femoral epiphysis and plate were normal, but the femoral neck appeared slightly broader than normal. Unfortunately, no lateral roentgenograms were made. For the next two years, the boy was lost to follow-up and was not examined again until three and one-half years after the injury. He was then in general good health and had no complaints. He had some restriction of internal rotation of the left hip (120 degrees according to the method of Campbell). The roentgenograms (Figs. 1-D and 1-E) showed a nearly normal joint

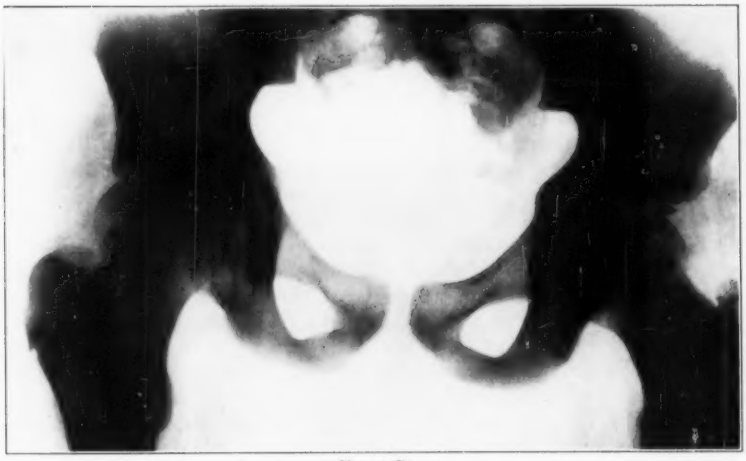

FIG. 1-D

Anteroposterior roentgenogram made three and one-half years after injury.

FIG. 1-E

Lateral roentgenogram made three and one-half years after injury.

space, but the femoral head was flattened and enlarged. The femoral neck was shorter and broader than on the right, and the epiphyseal plate was irregular. Slight osteoporosis was present.

This patient can be considered to have shown a good end result according to the measuring system of Ratliff because he has no pain, performs normal activities, shows no great distortion by roentgenograms, and merely has slight limitation of internal rotation. The roentgenographic changes in this case are not typical of a true complete avascular necrosis of the femoral head, there being simple enlargement of the head and neck, or coxa magna [6]. Degenerative arthritis of this hip must be anticipated sooner or later.

## DISCUSSION

The severity of the injury and the interval between dislocation and reduction are the most important factors that influence the frequency and extent of the avascular necrosis of the femoral head. In the series of Merle d'Aubigné and

Cormier, in adults, no necrosis occurred if reduction was done within a day of the injury, whereas necrosis occurred in two-thirds of the cases if reduction was delayed. In children, the lesser incidence of necrosis, estimated by Mason as 10 per cent in all reported cases, seems to be related to age.

The extent of the vascular damage is probably related to the manner of injury. In a posterior dislocation, which occurred in this patient and is the usual type, the femur is flexed and adducted at the time of injury. The head is forced superiorly and posteriorly, detaching the superior and posterior portion of the capsule from the ilium. This displacement tends to spare the main vessels supplying the femoral head, in contrast to an anterior dislocation in which the posterior portion of the capsule, in which a significant part of the vascular supply to the femoral head runs, is torn.

In the patient under discussion the minor alterations in the architecture of the femoral head are evidence of avascular necrosis, but of only minimal extent, not comparable with the usual cases of Legg-Calvé-Perthes disease. This degree of necrosis may have been directly due to the sparing of most of the vessels to the femoral head, since the long interval between injury and reduction undoubtedly would have increased the likelihood of aseptic necrosis. It is unlikely that the vessels in the ligamentum teres play any role in the vascularization of the femoral head during childhood [11], and the tearing of this ligament during dislocation would not appear to be an important factor in the incidence of aseptic necrosis.

## SUMMARY

A case of traumatic dislocation of the hip joint in a boy is reported. Follow-up, after three and one-half years, revealed a slight coxa magna, but more extensive evidence of avascular necrosis was not found despite a long delay between injury and reduction of the dislocation.

## REFERENCES

1. Banks, S. W.: Aseptic Necrosis of the Femoral Head Following Traumatic Dislocation of the Hip. A Report of Nine Cases. J. Bone and Joint Surg., **23**: 753-781, Oct. 1941.
2. Campbell's Operative Orthopaedics. Ed. 2, Vol. I, p. 13. Edited by J. S. Speed and Hugh Smith. Buenos Aires, Editorial Beta, 1955.
3. Cheynel, Jean: Introduction à la pratique chirurgicale de la hanche, p. 77. Paris, Gaston Doin et Cie., 1954.
4. Chigot, P. L., and Esteve, P.: Traumatologie infantile, pp. 5-245. Paris, Expansion Scientifique Française, 1958.
5. Dale, G. G., and Harris, W. R.: Prognosis of Epiphysial Separation. An Experimental Study. J. Bone and Joint Surg., **40-B**: 116-122, Feb. 1958.
6. Howorth, M. B.: The Osteochondroses. *In* Advances in Pediatrics. Edited by S. Z. Levine, A. M. Butler, L. E. Holt, Jr., and A. A. Welch. Vol. III, p. 304. New York, Interscience Publishers Inc., 1948.
7. LeMoine, André: Vascular Changes after Interference with the Blood Flow of the Femoral Head of the Rabbit. J. Bone and Joint Surg., **39-B**: 763-777, Nov. 1957.
8. Leriche, André: Bases de la chirurgie physiologique. Essai sur la vie végétative des tissus, p. 47. Paris, Masson et Cie., 1955.
9. Lewis, O. J.: The Blood Supply of Developing Long Bones with Special Reference to the Metaphyses. J. Bone and Joint Surg., **38-B**: 928-933, Nov. 1956.
10. Mason, M. L.: Traumatic Dislocation of the Hip in Childhood. Report of a Case. J. Bone and Joint Surg., **36-B**: 630-632, Nov. 1954.
11. Matthiash, H. H.: Reifung und Entwicklung in ihren Beziehungen zu Leistungsstörungen des Haltungs-und Bewegungsapparates, p. 133. *In* Handbuch der Orthopädie. Edited by G. Hohmann, M. Hackenbroch, and K. Lindemann. Stuttgart, Georg Thieme, 1957.
12. Merle d'Aubigné, Robert, and Cormier: Nécrose traumatique de la tête du fémur en dehors des pseudarthroses. Rev. Chir. Orthop., **42**: 246-267, 1956.
13. Ratliff, A. H. C.: Pseudocoxalgia. A Study of Late Results in the Adult. J. Bone and Joint Surg., **38-B**: 498-512, May 1956.
14. Smith, W. S.; Ireton, R. J.; and Coleman, C. R.: Sequelae of Experimental Dislocation of a Weight-Bearing Ball-and-Socket Joint in a Young Growing Animal. Gross Alterations in Bone and Cartilage. J. Bone and Joint Surg., **40-A**: 1121-1127, Oct. 1958.
15. Stewart, M. J., and Milford, L. W.: Fracture-Dislocation of the Hip. An End-Result Study. J. Bone and Joint Surg., **36-A**: 315-341, Apr. 1954.
16. Trueta, Joseph: The Normal Vascular Anatomy of the Human Femoral Head During Growth. J. Bone and Joint Surg., **39-B**: 358-394, May 1957.
17. Watson-Jones, Reginald: Fractures and Joint Injuries. Ed. 4. Vol. 1, pp. 81-83; Vol. 2, pp. 664-678. Edinburgh, E. and S. Livingstone Ltd., 1955.

# X-Ray Control for Operations on the Hip

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Methods for obtaining lateral roentgenograms of the hip during operations have always posed a problem. The difficulties in obtaining comparable exposures in series, the danger of contaminating the operative field, and the hazards of excessive exposure to personnel have all contributed to this problem. The method to

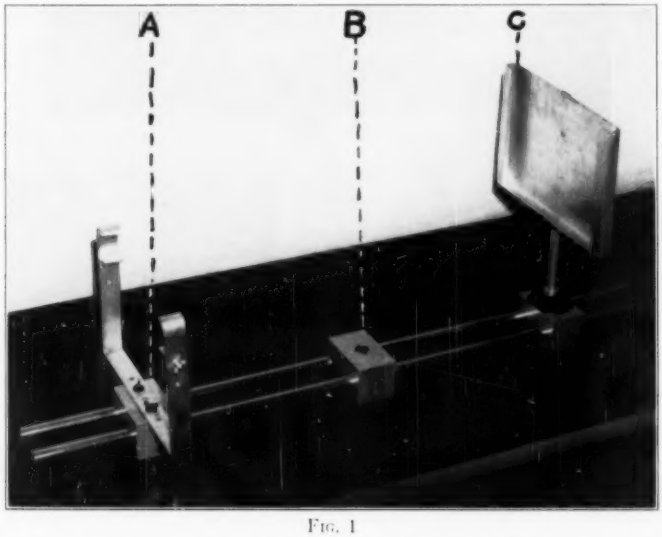


FIG. 1

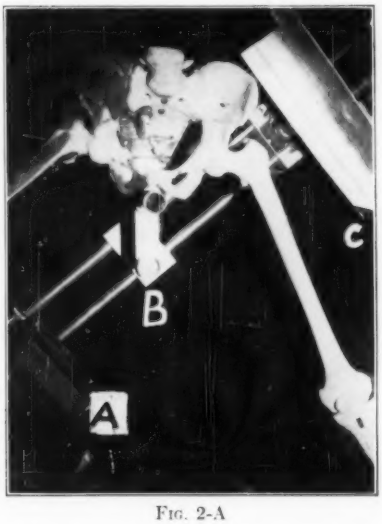


FIG. 2-A

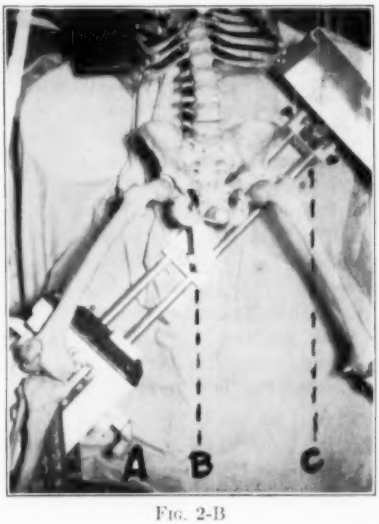


FIG. 2-B

* Deceased.

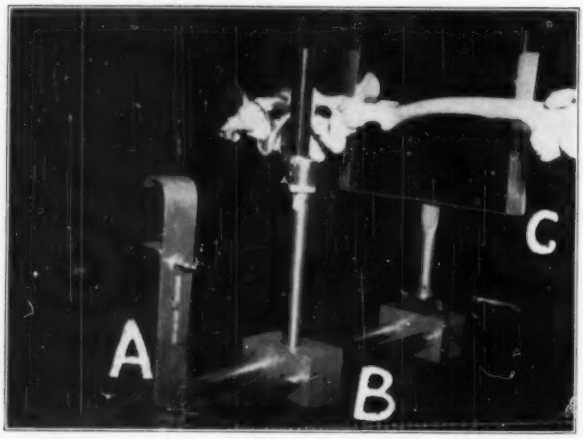


FIG. 2-C

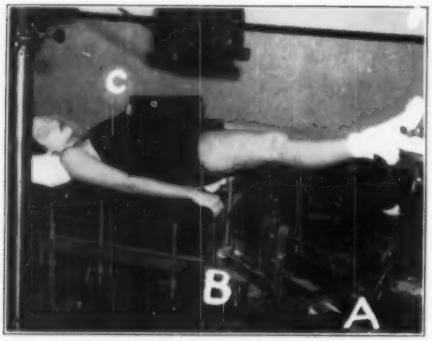


FIG. 3

FIG. 4

be described was designed to fulfill the requirements while using conventional apparatus, with a single attachment added. This device, like the photographer's enlarging machine, holds the source of the rays, the hip, and the film in a fixed, predetermined position. It consists of three blocks of aluminum, three by three by five inches, transfixed by two parallel bars, fifty inches long and one inch in diameter. Smaller holes for set screws were drilled in each block. The central block has a hole cut in it to permit the sacral-rest upright of the table to pass through it, thus fixing it to the table. One end block holds a clamp for the tube head; the other supports a cassette holder (Fig. 1). The clamp that cradles the tube head is shaped to fit the machine being used. It can be readily bent from bar aluminum or iron and is screwed to block A (Fig. 1). The cradle holds the tube head so that the central roentgen-ray beam is directed parallel to the top of the fracture table, but four inches above it so that it will center on the hip.

The cassette holder is made of light metal or wood and fixed to a standard that keeps it one-half inch above the top of the fracture table. It is fixed to the aluminum block in a manner that permits easy removal and replacement after each exposure. Instead of screw holes, slots were cut into the base of the standard. This permits the unit to slide on and off the block when the restraining wing nuts are loosened. The apparatus is swung so that the bars run under the hip, and it is locked in this position by means of a thumb screw. The preferred tube-film and target-film distances are obtained by sliding the blocks on the parallel bars to the proper positions where they, too, can be locked.

This apparatus, although flexible, enables the essential parts that are involved in the roentgenographic examination to be maintained in the same position throughout the operation. The central roentgen-ray beam is directed parallel to the bars and strikes the film perpendicularly. If the patient is placed on the table with the perineum against the perineal post, the localizer will direct the roentgen-ray through the hip (Figs. 2-A, 2-B, and 2-C). Since the same technical factors are maintained throughout the operation, the exposure factors that were found satisfactory in the pilot film can be repeated throughout the examinations. This eliminates much of the guesswork and yields results that are standard (Fig. 4). The apparatus is set up prior to the operation, so that no maneuvering is necessary during the operation except for the changing of the cassettes. Furthermore, the whole assembly can be draped, and the cassettes can be changed without disturbing the surgical field. By mechanical holding of the cassette, it is not necessary to subject a person to unnecessary radiation.

# Chondrodysplasia (Ollier's Disease)

## Report of a Case with a Thirty-eight-Year Follow-up

BY MATHER CLEVELAND, M.D., AND J. WILLIAM FIELDING, M.D., NEW YORK, N. Y.

This is a study of a case, followed for thirty-eight years, of chondrodysplasia of the type known as Ollier's disease. This patient was first observed in 1920, and the case was reported in September of 1928, when the patient was ten years of age. When the patient was last seen he was forty, and except for the obvious deformity, has experienced no ill-effects.

F.H. was first seen in July 1920, when he was two years old. There was a history of deformity of the left leg that was first noted when the patient was six months old. The child was essentially normal on examination, except for the left lower extremity which was two inches shorter than the right. The left foot was in varus, and the tibia was markedly bowed laterally (Figs. 1, 2, and 3).

In the ensuing years disparity in limb length increased. In June 1924 the left limb was six inches shorter. There was moderate anterolateral bowing of the upper one-third of the

FIG. 1

FIG. 2

FIG. 3

Figs. 1, 2, and 3: Roentgenograms, made in July 1920, when the patient was two years of age. The long bones of the left leg are short. The distal inch of the tibia is enlarged, and in this area there is a deficiency of bone structure—it is apparently mostly cartilaginous. A similar situation exists in the other long bones of this extremity. The changes are most marked in the metaphysis (reprinted from Chondrodysplasia by Mather Cleveland. Surgery, Gynecology and Obstetrics, **47**: 339, 1928).

FIG. 4

FIG. 5

FIG. 6

Fig. 4: The patient at the age of forty years (1958).

Figs. 5, 6, and 7: Roentgenograms made in June 1958, when the patient was forty years of age. The bones have grown in length. In some areas the cartilaginous masses have been replaced by mature bone. The deformity and shortening were present. There was no evidence of malignant degeneration.

FIG. 7

femur and marked posterolateral bowing of the distal one-third of the tibia. The ends of these bones were enlarged. The foot was rotated laterally 90 degrees. Function at the knee and hip was normal.

In June 1925 osteotomy of the tibia was done to correct the deformity; the bone was divided a little below its center where it was found to be quite brittle. Healing was uneventful. In January 1927 a biopsy of the lower tibial epiphysis revealed cystic degeneration of cartilage.

When last seen in June 1958 the patient's general condition was excellent (Fig. 4). The patient was asymptomatic, had almost no physical or psychological disability from the deformity, and was able to do a full day's work without difficulty. The left lower extremity was thirteen inches shorter than the right. The shortening is compensated for by a toe-to-groin brace with a platform on which the shortened limb rests. There was mild lateral bowing of the left femur and, whereas the shaft of the tibia was relatively straight, there was rather marked varus deformity of the ankle and a cavus deformity of the foot. Motion at the knee and hip was normal.

Roentgenograms in June 1958 revealed the same data as previously, except for the expected enlargement of the bones as the patient grew in stature. In most areas the cartilaginous masses were replaced by mature trabeculated bone, but the over-all general deformity of the bones was not changed (Figs. 5, 6, and 7).

## SUMMARY

This is a case of chondrodysplasia of the Ollier type. It is an asymmetrical cartilaginous dysplasia, with resulting skeletal deformity confined (in this patient) to the left lower extremity. The condition is deforming but does not appear to be seriously handicapping to the patient.

## REFERENCES

1. OLLIER, L. L. X. E.: Dyschondroplasie. Lyon Méd., **93**: 23-25, 1900.
2. CLEVELAND, MATHER: Chondrodysplasia. Surg., Gynec., and Obstet., **47**: 338-345, 1928.

# Proceedings

## THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS
## 1959 MEETING
## SCIENTIFIC EXHIBITS

**New Training Materials for the Certified Orthotist and Prosthetist: A Report to the Orthopaedic Surgeon.** LESTER A. SMITH[1], Assistant Director of the American Board for Certification of the Prosthetic and Orthopedic Appliance Industry, Inc.; JOHN A. DEBENDER, C. O.; ALFRED DENISON, C. P.; GEORGE H. LAMBERT, C. O. and P.; FRED J. ESCHEN, C. O. and P.; RICHARD BIDWELL, C. O. and P.; HOWARD R. REINHERZ, C. O.; and TED W. SMITH, C. O. and P. presented a survey on sources of information and reference aids relating to artificial limbs and braces. The importance of such aids was illustrated by a display of certain modern prostheses and braces for which manuals are available and which require detailed instructions.

It was pointed out that much of our knowledge of artificial limbs and braces has come to us verbally from the orthopaedic surgeon and the orthotist-prosthetist in their cooperative effort to assist the handicapped.

The picture is changing rapidly: the certification movement has encouraged yesterday's craftsmen to become certified orthotists and prosthetists with a sense of professional responsibility, and has encouraged the development of training procedures for new recruits to this field. On the university level, the courses in prosthetics at New York University and the University of California at Los Angeles, and now at Northwestern University, has brought to the printed page much of the painfully accumulated knowledge of the past.

In all of this progress, the orthopaedic surgeon has played a leading role as friend and sponsor of the certification movement. This exhibit has been prepared for his consideration as a review of the printed reference aids presently available.

### SOURCES OF INFORMATION

The sources of information and directories in this field are:

*American Board for Certification*, 919 18th Street, N.W., Washington 6, D. C. The Board annually conducts examinations to certify the ethical and skilled prosthetists or orthotists, or both, and maintains in its Washington headquarters extensive biographical and reference files on these persons. The Board is publisher of two official registries (one relating to certified facilities and the other to the certified technicians). Note that three of the seven members of the Board serve by nomination of the Executive Committee of The American Academy of Orthopaedic Surgeons.

*Prosthetics Research Board, National Research Council**. This is the successor to the Advisory Committee on Artificial Limbs.

The scope of the Board includes both orthopaedic appliances and prosthetic devices. Research under its supervision is carried out at the University of California at Berkeley and at Los Angeles, New York University, Northwestern University, and the University of Michigan (orthopaedic appliances).

*Orthopedic Appliance and Limb Manufacturers Association*, 919 18th Street, N.W., Washington 6, D. C. This association was founded in 1917 as a result of a call from the Council of National Defense, which brought twelve artificial-limb manufacturers to Washington for a conference. In the ensuing years, the scope of this Association has broadened to include orthopaedic appliances as well as artificial limbs. It serves a dual function—as a trade association and as the professional association in this field. It is the publisher of the "Orthopedic and Prosthetic Appliance Journal". Its annual convention, the National Assembly, is the national professional and technical convention of those people interested in the making and fitting of artificial limbs and orthopaedic appliances.

*United States Veterans Administration*, 252 Seventh Avenue, New York, N. Y. The Prosthetics Research Center is a unit of the Veterans Administration Prosthetic and Sensory Aids Service. Of particular importance is the Testing and Development Laboratory.

1. 919 18th Street, N.W., Washington 6, D. C.

* Since this exhibit was prepared, the Prosthetics Research Board has been discontinued and its responsibilities have been assigned as follows:

1. *Research*: The Committee on Prosthetic Research and Development, National Research Council, 2101 Constitution Avenue, Washington, D. C.

2. *Training and Information*: Committee on Prosthetic Education and Information, National Research Council, 2101 Constitution Avenue, Washington, D. C.

*The Research and Development Division* is also a unit of the Veterans Administration Prosthetic and Sensory Aids Service. This division maintains a valuable exhibit of contemporary appliances and a small but very good library.

*International Prosthetics Center*, Esplanaden 34, Copenhagen, Denmark. This news center collects data on prostheses, braces, and other technical aids. It is affiliated with the International Society for the Welfare of Cripples.

### Directories

*Official Registry of Prosthetic and Orthopedic Appliance Facilities.* Published annually by the American Board for Certification, Washington, D. C. (Limited free distribution.) In the combined offices maintained by this Board and the Orthopedic Appliance and Limb Manufacturers Association (OALMA) in Washington, will be found personnel records on approximately 1,500 limb and brace technicians and information on approximately 500 firms in this field.

### Abstracts

*Rehabilitation Literature.* The National Society for Crippled Children and Adults. Published monthly at Chicago, starting January 1959.

This is a continuation and expansion of a mimeographed bulletin issued by the Society, 2023 West Ogden Avenue, Chicago 12, Illinois.

Much of the previous material is included in Graham, E. C., and Mullen, Marjorie M.: *Rehabilitation Literature 1950-1955.* New York, The Blakiston Division, McGraw-Hill Book Co., Inc., 1956.

*Prosthetics Abstracts.* In late 1954, the Advisory Committee on Artificial Limbs (precursor of the Prosthetics Research Board) initiated a bibliography of the literature of the past ten years. This was discontinued because of lack of funds. The material which was collected under the supervision of Bryson Fleer, editor of *Artificial Limbs*, is on file in his office, in Washington, D. C.

### Books and Manuals

*Orthopaedic Appliance Atlas, Volume I.* Ann Arbor, J. W. Edwards, 1952. This is a basic text on orthopaedic appliances, published under the auspices of The American Academy of Orthopaedic Surgeons, containing a historical review of bracing, a discussion of materials and their use, and an illustrated catalogue of braces for the back, arms, and legs.

*Orthopaedic Appliance Atlas, Volume II—Prosthetics.* Work is in progress on Vol. II of the Atlas, again under the auspices of The American Academy of Orthopaedic Surgeons, the United States Veterans Administration, and the Office of the Surgeon General, United States Army. Information of its scope and progress may be had by writing to the Committee on Advances in Prostheses, OALMA, 919 18th Street, N.W., Washington 6, D. C.

*Amputation Prosthesis.* By Thomas, Atha, and Haddan, Chester C. Philadelphia, J. B. Lippincott Co., 1945. 305 pages. Out of print, but available in many medical and specialized libraries. This is one of the best-written and most readable books to appear, and is an excellent starting point for a review of prosthetic literature.

*Amputation Prosthetic Service.* By Daniel, Earle H. Baltimore, The Williams and Wilkins Co., 1950. 327 pages. $7.00. A practical book, whose usefulness is enhanced by the reprinted material it contains.

*Human Limbs and Their Substitutes.* Prepared under the sponsorship of the Advisory Committee on Artificial Limbs, by Paul E. Klopsteg, Philip D. Wilson, and others. New York, Toronto, London, McGraw-Hill Book Co., Inc. 844 pages. Illustrated. $12.00. The scope of this book is explained by the subtitle: Presenting Results of Engineering and Medical Studies of the Human Extremities, and Application of the Data to the Design and Fitting of Artificial Limbs and to the Care and Training of Amputees. The book incorporates data from the extensive research program of the last eight years, sponsored jointly by the Veterans Administration and the Surgeon General, Department of the Army. Some gaps are apparent, but they are being filled in gradually by articles in periodicals.

*Manual of Upper Extremity Prosthetics.* Compiled by the Staff of the Artificial Limbs Project, University of California at Los Angeles. 1958. Second edition. 304 pages.

*Functional Bracing of the Upper Extremities.* Miles H. Anderson. Springfield, Illinois, Charles C. Thomas, 1958. 463 pages.

*Manual of Above-Knee Prosthetics.* University of California, Los Angeles, School of Medicine, Prosthetics Education Program. 1957. This manual appears in two editions, one for physicians and therapists; the other for prosthetists.

*Management of the Above-Knee Amputee.* New York University Post-Graduate Medical School. 1959.

### For the Patient

*Advice to the Amputee.* By P. B. Burnham, M.D. Available through OALMA, 919 18th Street, N.W., Washington, D. C.

*Maintenance and Care of the Prosthesis.* By Charles A. Hennessy. Available through OALMA, 99 18th Street, N.W., Washington, D. C.

PERIODICALS

*Artificial Limbs: A Review of Current Developments.* Published twice a year by the Prosthetics Research Board, 2101 Constitution Avenue, N.W., Washington, D. C.

*American Journal of Occupational Therapy,* 250 West 57th Street, New York 19, N. Y. This journal contains some technical articles on the current developments in orthotics.

*American Journal of Physical Medicine.* Bi-monthly publication of The Williams and Wilkins Co., Baltimore 2, Maryland. This journal occasionally contains technical articles concerning the development and application of orthotic devices.

*Archives of Physical Medicine and Rehabilitation,* 30 North Michigan Avenue, Chicago 2, Illinois. Included in this journal are occasional articles on the development and use of orthopaedic appliances.

*Braces Today.* Monthly newsletter by the Pope Foundation, Inc., 197 South West Street, Kankakee, Illinois. New developments in the field of orthotics are presented in this newsletter.

*The Journal of Bone and Joint Surgery* (American Volume and British Volume).

*Journal of Rehabilitation.* Published bi-monthly by the National Rehabilitation Association, 1025 Vermont Avenue, Washington, D. C. Although this publication must cover a very broad field, space is found for excellent summaries of events and publications pertaining to orthotics and prosthetics.

*Orthopedic and Prosthetic Appliance Journal.* Quarterly journal of the Orthopedic Appliance and Limb Manufacturers Association, 919 18th Street, N.W., Washington 6, D. C. Technical articles on the fitting and fabrication of appliances appear in this journal.

*The Physical Therapy Review.* American Physical Therapy Association, 1790 Broadway, New York 19, N. Y. This monthly publication includes articles on orthopaedic appliances.

*Rehabilitation.* Quarterly journal of the British Council for Rehabilitation, Tavistock House (South), Tavistock Square, London, W.C. 1, England. Informative articles about the use of orthopaedic appliances in rehabilitation throughout the world are presented in this journal.

**Industrial Amputee Rehabilitation.** DR. CHARLES O. BECHTOL[2], the author of this free fifty-page booklet, said that the purpose of this book was to compile material that will help the amputee return to his employment and to his family with such a high degree of function that he will not be considered disabled but will return to his normal place in society. The successful fitting of the prosthesis is not enough. Nor is the success due to any single spectacular step in recovery. A logical process must be carried out step by step so that the amputee finally gains active use of his prosthesis and has been rehabilitated in the broadest sense of the word. In this field it can be truly said that trifles make perfection but perfection is no trifle.

The factors in the successful rehabilitation of the amputee are: (1) correct surgery; (2) postoperative care—mobilizing the joints, preventing flexion contractures, and allowing for proper shrinkage of the stump; (3) psychological preparation of the amputee through a careful explanation of the process of his rehabilitation (demonstration by successfully fitted similar amputees have been quite helpful in this respect); (4) prescription of the prosthesis, carried out by blending the skills of the physician, therapist, and prosthetist as a team; (5) adequate prosthetic training to ensure the successful use of the prosthesis; and (6) productive job placement, utilizing existing or developed work skills.

In prescribing the prosthesis the following items are most important: the level of the amputation; the patient's general health and other disabilities; the patient's neuromuscular ability; the patient's occupation and the activities he will carry out in his daily living; the psychological adjustment; and the prosthetic device, which must be durable and easily maintained in good operating condition.

The prescription contains specific recommendations for all parts of the prosthesis, considering all the purposes for which the prosthesis must be utilized and the training that the amputee is to receive after the prosthesis has been correctly fitted. When the prosthesis is received, a check-out procedure is carried out to be sure that the prosthesis is functionally adequate. The amputee then receives training in the control of the various parts of the prosthesis. After this he receives further training in the use of the prosthesis through the activities of daily living and those related to his occupation.

After the training period, the amputee is again examined to be sure that he can accomplish all the necessary activities. When the amputee has returned to his employment there is the problem of the acceptance of the amputee by the employer, fellow employees, and the amputee's own family. Amputees should have follow-up examinations at intervals to determine if the prosthesis is in good operating condition.

2. University of California Medical Center, Los Angeles 24, California.

The medical exhibit itself outlined factors in successful amputee rehabilitation, prosthetic-prescription considerations, and the results of a study of 565 amputee patients referred to the industrial accident rehabilitation centers operated by Liberty Mutual Insurance Company.

**Calcium Phosphorus Metabolism in Bone.** Dr. Floyd E. Bliven, Jr.[3], and Mr. Algernon R. Allen were interested in the diagnosis of many metabolic diseases in bone by laboratory data. The exhibit was presented primarily as a teaching aid, emphasizing the significance of normal as well as abnormal values in diagnosis. In this exhibit a table of switches allowed one to record the expected chemical findings in each of ten diseases. By placing a disease-identified card in a slot, a contact box was modified to present the pattern of expected laboratory values as lighted squares in a chart. Squares were lighted only in each column in which the correct level was designated. Laboratory values are often more helpful when presented in this way as a pattern than when considered as individual determinations.

**Epiphyseal Fractures: A Microscopic Study of the Healing Process in Rats.** Dr. H. R. Brashear, Jr.[4], presented an exhibit based on a study of closed adduction fractures through the distal femoral epiphysis of young rats. Photomicrographs and diagrams illustrated the course of the fracture line through the epiphyseal plate. On the distraction (convex) side of the fracture the break passed through the zone of hypertrophic cartilage cells. On the compression (concave) side a small triangular fragment of metaphyseal bone was included with the epiphyseal fragment. During the healing process marked widening of the cartilage plate distal to the fracture took place. In some instances the cartilage plate became so wide that a separate ossification center developed within it. This was demonstrated by drawings and photomicrographs.

**Modified Risser Localizer Technique Employing a Standard Table with Some Simple Accessories.** Dr. Louis W. Breck[5] demonstrated how the principle of using strong head and foot traction together with a localized pressure pad could be adapted to the standard Albee-Comper table. A head-traction device, allowing more room for the head-halter traction and employing a simple windlass, was constructed. The patient is put on the table with the feet in traction in the usual way. The feet are placed in the regular foot holders and held there with a muslin bandage. Traction is made on the head by means of the head halter and windlass. A Risser pressure pad is made, and then pressure is made against this by an ordinary triangular automobile jack to which an extension has been fastened. Effective localized pressure is made in this way. The exhibit showed a detailed scale model of the fracture table, the head-traction device, and the jack for making the pressure. Photographs showed the actual apparatus in use on a patient, and appropriate legends described the device. One set of roentgenograms illustrated the patient's scoliotic curve before and after correction.

**Cine-arthrography (Radiography) in Prosthetic Hip Joint Reconstructions and Arthroplasties.** Dr. Joseph E. Brown[6], Dr. H. F. Inderlied, and Dr. George Wright demonstrated the roentgen-ray equipment currently used and also mentioned the radiation factors. Cine-arthrography, or roentgenography, does not use the image-intensification method.

The equipment includes a routine, high-voltage, 120 to 130 roentgen-ray tube, using seventy-five milliamperes. The tube-screen distance is thirty inches, and there is an added aluminum filter amounting to two millimeters.

A special fluoroscopic screen, the Patterson B-2, is used, and the image is then transferred by way of a 45-degree front surface angled mirror and is directly photographed by a special thirty-five millimeter camera with an F 0.7 lens. The special camera is electrically integrated so that the roentgen ray is only emitted when a film is being made.

The routine of the examination of the patient was also demonstrated, showing the ranges of motion. In view of the fact that this is special equipment and not adjustable conveniently to follow a patient in walking, a push-pull manipulation is used to simulate weight-bearing.

The eight cases that were demonstrated by cine-roentgenography were also demonstrated by conventional roentgen-ray transparencies. Pathological specimens were also included. Preoperative cases of malum coxae senilis, demonstrating the restricted range of motion and a normal study were shown. The cases presented included a cup arthroplasty, a Vitallium Judet short-stem prosthesis, an Austin Moore prosthesis inserted in a patient who had aseptic necrosis secondary to a fracture of the neck of the femur, an Austin Moore prosthesis in a Charcot joint, and a McBride prosthesis in an old fracture-dislocation, in which there had been previous surgery, including a Vitallium cup arthroplasty complicated by infection and removed six months after its insertion in 1941. There was also a Charcot joint with a McBride prosthesis in place; the last case shown comprised aseptic necrosis secondary to a fracture

3. Medical College of Georgia, Eugene Talmadge Memorial Hospital, Augusta, Georgia.
4. University of North Carolina School of Medicine, Chapel Hill, North Carolina.
5. 526 Montana Avenue, El Paso, Texas.
6. 10515 Carnegie Avenue, Cleveland 6, Ohio.

of the femoral neck with an Eicher prosthesis. The roentgen-ray transparencies demonstrated zones of sclerosis or absorption, or both, indicating that, when these are present there is motion or slippage or failure of anchorage of the prosthesis in the host bone. These motions and the changes can be adequately demonstrated and recorded by routine roentgenograms.

It is the conclusion of the authors that cine-arthrography is of no additional clinical value in the study of prosthetic hip-joint reconstructions. It is, however, of great teaching value.

When motion is demonstrated between the prosthetic stem and the femoral shaft in conventional roentgenograms it is confirmed by cine-arthrography. However, cine-arthrography does not shed any additional light. Considering the roentgenographic exposure factors —namely, five conventional views of the hip, totaling 10 Roentgen units—compared with the cinematic studies currently employed, equaling 30 Roentgen units, it is the authors' opinion that the exposure in cine-arthrography, although not prohibitive, is not justified.

Radiation hazards to the examining physician are not at present a deterrent factor. The use of the image intensifier does, unquestionably, reduce the radiation hazard, but also reduces the size of the field studied. With the method currently employed, a full twelve-by-thirteen-inch screen can be covered and recorded.

Current difficulties as experienced in the reduction of the thirty-five-millimeter to sixteen-millimeter film and the high cost of the examination do not make cine-arthrography of the hip a practical clinical examination, but cine-arthrography is of infinite value when used for teaching.

**Acetabular Gauge for Use in Prosthetic Replacement and Pocket Size Goniometer for Use in Operating Room or Clinic.** Dr. Warner D. Bundens, Jr.[7].

**Conservative Treatment of Fractures in the Hand.** Dr. Preston J. Burnham[8] presented detailed pictures, in color, of the more common errors in management responsible for misalignment of fractures of the phalanges and metacarpals. These poor techniques include mass closure of the hand into a fist with plaster cover, short splints for the finger only, splinting out in the unphysiological position of extension on a tongue blade, and the banjo splint so reminiscent of the torture devices of earlier days.

There were detailed anatomical drawings in color of the anatomy of the bones, joint structures, long (extrinsic) and short (intrinsic) muscle-tendon systems which must be taken into consideration when reducing and immobilizing fractures of these fine bones.

Dr. Burnham described a new aluminum splint, combined with a plaster slab, used in immobilizing fractures of these bones. The technique is somewhat in reverse of classic procedures. First, anesthesia is initiated and then the aluminum and plaster splints are fitted to the hand and forearm, where they are fixed by roller bandage and the plaster is allowed to harden. The forearm, wrist, and hand are now immobilized on the device, and both hands of the operator are free to apply tape to the digit, gently reduce it, and place it on the splint with tape fixation only.

The procedure is performed by the unaided operator for most fractures. Compound and severely comminuted fractures are reduced and splinted with equal ease, and dressings are easily changed. The basic principles are: to splint the entire injured ray in as near a position of rest as possible, and to splint the hand and forearm first, leaving the injured bone until the last.

Photographs of clinical material and roentgenograms further illustrated the technique.

**New Plastic Artificial Legs.** Capt. Thomas J. Canty, M.C., U.S.N.[9], Capt. R. C. Doolittle, M.C., U.S.N., and Dr. Eugene E. Bleck presented an exhibit in which six descriptive panels were arranged on a raised platform. Listed on one of the panels were some of the advantages of the new Navy plastic artificial limbs: comfort, because of the soft, semiflexible, closed end, total-weight-bearing socket; a functional foot and knee; skeletal bearing in total-weight-wearing socket; earlier fitting in a soft, total-weight-bearing socket; good cosmetic acceptance; hygienic, because of rot-resistant and waterproof characteristics; usefulness in any climate; mass production by semiskilled labor; low cost in man hours and materials; and adaptability, durability, and good strength-weight ratio.

Another panel consisted of color transparencies depicting various problems relating to the stump and successfully fitted with the Navy's plastic, semiflexible, soft, closed-end, total-weight-bearing socket: scarring, ulcers, chronic skin conditions, and prominent bone prominences. A scaled-down model of an accelerated walking machine was in operation on the platform. This machine is used in testing feet, shin, and knee mechanisms. Two panels were devoted to showing the various elements of the above-the-knee and below-the-knee prostheses used in the Navy. The standard Navy below-the-knee artificial leg was shown immersed in a tank of water to illustrate the waterproof characteristics of Navy artificial legs. Photographs

7. Quarters F-11, United States Naval Hospital, Philadelphia 45, Pennsylvania.
8. 508 E. South Templeton Street, Salt Lake City 2, Utah.
9. Navy Prosthetic Research Laboratory, U. S. Naval Hospital, Oakland 14, California.

alongside the tank showed a patient swimming and taking a shower while wearing the artificial leg.

In addition to the display, a short lecture was given, somewhat enlarging the points illustrated by the exhibit. This lecture was concluded by a brief demonstration of the production and assembly of the standard Navy artificial legs. Three amputees using Navy prostheses assisted in the demonstration.

**The Long-Term Radiographic End Results of Calvé-Legg-Perthes Disease.** Dr. Earnest B. Carpenter[10] and Dr. Douglas O. Powell said that their conclusions and observations are based on a study of ninety cases of Calvé-Legg-Perthes disease. End-result roentgenograms, made as late as twenty-five years after completion of treatment, were used as the basis of this study and for the conclusions reached. Since the authors were aware that controversy exists as to the best treatment of Perthes disease, no attempt was made to compare the end result of one type of treatment with another. The cases were divided into three groups, depending on the amount of destruction of the capital femoral epiphysis at the time of admission, with Group I having minimal changes, Group II moderate changes, and Group III extensive changes. There were seventy-six boys and fourteen girls, a ratio of five boys to one girl. Fifty-four per cent of the patients were over the age of seven at the time of admission. Only thirty cases were in Group I (minimal changes), which suggests that greater emphasis is needed to impress practitioners with the need for a high index of suspicion of this condition, thus permitting earlier diagnosis and treatment before the changes in the femoral head are irreversible. All patients in Group I had an excellent end result, and all patients in Group III (advanced changes) had a poor end result, regardless of the method of treatment. All patients below the age of five had an excellent end result, and all over the age of eight, a poor end result. Restriction of weight-bearing during the period of epiphyseal destruction is necessary if an essentially normal-appearing femoral head is to be the desired end result. The ischial weight-bearing brace was not an effective means of preventing weight-bearing in this group of cases. The authors stressed the importance of early diagnosis and restriction of weight-bearing to provide a good end result and prevent irreversible changes in the femoral head.

**Experimental Data on the Healing of Ruptured Ligaments.** Dr. Mack L. Clayton[11] and Dr. Gordon J. Wier, Jr., said that after severe injury with complete rupture of a ligament, instability of the joint often occurs because the ligament fails to heal with proper length and strength. The most common method of treatment has been plaster immobilization. Recently, several reports have advocated early operation to suture the torn ligament.

The problem is: after division, is the sutured ligament stronger than the unsutured?

The method was to first obtain control studies on the tensile strength of medial collateral ligaments in knees of adult dogs. This was measured by the force necessary to disrupt the ligament. The control conclusions were:

1. There is marked variation in strength of the medial collateral ligaments in different dogs.
2. There was no significant variation between the right and left knee in the same dog.
3. All the ligaments disrupted at the ligamento-osseous junction, which normally represents the weakest link in the chain.

The medial and lateral collateral ligaments of both knees were horizontally transected at the joint line in dogs. The ligaments of one leg were sutured, and those in the other leg left open. Both legs were immobilized identically by intramedullary pins. The dogs were sacrificed and the disrupting strength of the medial ligaments determined at intervals of four days to nine weeks. Microscopic study was performed on lateral ligaments.

The results showed that: the sutured ligament is stronger at each test period; after six weeks no sutured ligament disrupted through the suture line; all unsutured ligaments parted at the line of previous section; and the microscopic picture at six weeks revealed the sutured ligament to be healed by continuous ligamentous fibers. The unsutured ligament still had a gap of fibrous tissue.

In conclusion, the authors stated that: (1) the tensile strength of the divided ligament repaired by suture is consistently stronger than the unsutured control; (2) after six weeks the suture line cannot be disrupted and the ligament parts through a normal area. The suture line is no longer the weakest link in the chain; and (3) at nine weeks the unsutured ligament still disrupts through the line of division—the weakest link in the chain.

**Committee on the Advancement of Automobile Safety. Prevention of Automobile Injuries.** Dr. Murray E. Gibbens[12] pointed out what can be done by safety engineering of automobiles and good driver education to diminish this major public health problem—automobile injuries.

10. 116 East Franklin Street, Richmond 19, Virginia.
11. 1855 Gaylord, Denver 6, Colorado.
12. Veterans Administration Hospital, Denver 20, Colorado.

In 1957, there were 38,000 deaths and about 2,000,000 injuries from automobile accidents. To emphasize these figures, it may be pointed out that there are over 100 deaths per day, or five each hour, and approximately fifty times this many injuries. About 100,000 of these injuries result each year in permanent disability, deformity, or invalidism of varying degree. Some victims lose the ability to be wage earners, and some become long-time nursing problems or permanent inmates of hospitals or nursing homes. Aside from death, injury, and pain, there is a tremendous economic loss because of automobile accidents.

Something must be done to correct and diminish this problem with which we are all faced. This is a problem for preventive medicine, public education, traffic and automobile safety engineers, state driver-licensing bureaus, police departments, and for each and every private citizen. The results of the traffic injuries become daily problems for our physicians and surgeons, frequently with special problems for the orthopaedic surgeon. In this connection, the orthopaedic surgeon also should be interested in prevention of injury as well as treatment.

The prevention of automobile injuries is summarized in six important categories:

1. Better driver education, which can be furnished in our high schools, by the American Automobile Association, and by cooperation of newspapers, radio, and television stations with our state and local police departments and civic safety organizations.

2. Better standards of driver qualification and licensing. Each driver should memorize and pass a test on the Good Driver's Code, such as that furnished with the exhibit. Good qualifications of vision, physical ability, and mental responsibility should be required and checked at reasonable intervals.

3. Stricter laws and enforcement, such as those in Connecticut (and elsewhere), have been shown to decrease the accident rates.

4. Better safety engineering in our cars is important. It is agreed that American cars have been greatly improved in the past few years, with better visibility, lower center of gravity, precision steering, and better brakes, as well as important safety features such as safety door latches, deep-dish impact-absorbing steering wheels (on some models), and foam-plastic padding of the dashboard.

5. Properly installed safety belts with shoulder straps is the most effective safety device of all when properly and consistently used. Much apathy and resistance to this device have been met because of indifferent automobile dealers and lack of public interest. Many dealers have felt that the showing or selling of seat belts in their sales rooms or garages would diminish the sales of automobiles. Yet, it has been shown by reliable statistics gathered by the Cornell University Medical College that the chances of survival without severe injury are at least 60 per cent better with average seat-belt installations. With the better installations, combined with an effective shoulder or chest strap for front-seat passengers, and other modern safety features, this survival rate should be still further improved.

6. Better regulated highway and traffic flow is also an important factor, and our highway engineers are constantly striving to improve highway conditions.

Each citizen and each physician is asked:

1. To write to his automobile manufacturing company, requesting the installation of safety features, and to ask for safety features and seat belts to be shown and distributed by the individual automobile dealers;

2. To help promote good driver education in all public high schools;

3. To promote the use of the Good Driver's Code by all state driver-licensing bureaus;

4. To keep his speed down.

The recommended Good Driver's Code, in essence is: (1) keep your car in mechanically good condition; (2) do not drive after drinking; (3) obey the speed laws; (4) don't drive if sleepy; (5) keep alert; (6) be courteous; (7) signal all turns and slow-downs; (8) do not drive too close to the car ahead; (9) slow down in bad weather; (10) avoid road-hogging; (11) watch the other driver; and (12) install seat belts. (There is much more to the code, and the complete code should be studied.)

**Committee on Instructional Courses. Clinical Data-Cases for Instructional Course Dinner Program.** Dr. Fred C. Reynolds[13], *Chairman.*

**Committee on Pathology. Lesions of the Epiphyseal Region.** Dr. Crawford J. Campbell[14], *Chairman.*

**The Differential Diagnosis of Spine Lesions Aided by Vertebral Body Biopsy.** Dr. Frederick S. Craig[15] set forth the following premises in reaching a diagnosis. Premise One: pain in the back not responding to five days of bed rest is either tumor, osteomyelitis, herniated nucleus pulposus, or rheumatoid arthritis, until proved otherwise. Premise Two: the tumor

13. 4960 Audubon Avenue, St. Louis 10, Missouri.
14. 721 Madison Avenue, Albany 8, New York.
15. 180 Fort Washington Avenue, New York 32, N. Y.

becomes evident as destruction in the vertebral body or posterior processes. Premise Three: the infection becomes evident first as narrowing of the disc space with subsequent destruction or bone production adjacent to the disc space. Premise Four: osteo-arthritis of the thoracic vertebra is seldom a cause of pain.

Roentgenograms of the entities discussed and proved by the premises were used to illustrate the talk, as were photographs of the steps in vertebral-body biopsy and photomicrographs of cores and pathological specimens.

**Spina Bifida: A Follow-up of 90 Cases.** Dr. Burr H. Curtis[16] and Dr. Earl Brightman presented a long-term survey of ninety cases of paraplegia and quadriplegia of congenital origin, made in a two-year study at the Newington Hospital for Crippled Children. The survey showed the orthopaedic, neurological, and urological problems and complications encountered. These were presented statistically and the over-all result of treatment as to psychological and sociological habilitation was stressed. The relationship of age, etiology, level of cord involvement, and other factors with the prognosis, treatment, complications, and results obtained were analyzed.

**Transplantation of Osteofemoral Caps in Three Categories.** Dr. Anthony F. DePalma[17], Dr. Blackwell Sawyer, and Dr. J. David Hoffman said that their experiment comprised transplantation of osteochondral caps in three types of grafts—autogenous, homogenous, and plasma-stored, homogenous osteofemoral caps. There were 155 dogs used in this experiment. The results clearly demonstrated that in the autogenous grafts, both the osseous and the cartilaginous portions are readily incorporated by the host. Most of the osseous portion of the graft stays alive; the remaining portion is replaced by bone from the host. The cartilage in the autogenous graft is still viable and functions well at the end of one year.

In the fresh homogenous graft, the entire osseous portion of the graft is replaced. However, the cartilage remains alive but in many of these specimens, after six to twelve months, there is definite evidence of deterioration of the cartilage. In this type of graft, 30 per cent of the specimens showed evidence of deterioration of the cartilage.

In the plasma-stored homogenous transplants, again, the osseous portion of the graft was completely replaced in all instances. However, there were several instances in which there was complete destruction of the graft. This may be the result of some immunological phenomenon. As in the second type of graft, we have many instances of failures of the cartilaginous portion of the graft. In this last type, 43 per cent of the grafts showed complete degeneration of the cartilage at the end of one year.

It is apparent that in the dog, osteochondral transplants do succeed in the autogenous graft. There is a high percentage of failures in the plasma-stored grafts, and a smaller percentage of failures in the fresh homogenous grafts.

**Subchondral Cysts: A Clinical and Experimental Study.** Dr. G. W. N. Eggers[18], Dr. E. Burke Evans, Mr. James K. Butler, and Dr. Johanna Blumel discussed the clinical and experimental observations relating to subchondral cysts. The section on clinical observations was concerned exclusively with subchondral cysts of the iliac acetabulum and, by case presentation, showed: that acetabular cysts are clinically important; that they may occur as early as the third decade, but are more common later; that they cause pain and warn of progressive hip destruction; and that through early detection and definitive treatment by surgical ablation the acetabulum may be restored, the pain relieved, the destructive process arrested, and hip invalidism prevented or forestalled. Details of the surgical procedure were shown in color transparencies. A special point was made of the importance of obliterating acetabular cysts prior to insertion of a prosthesis.

The experimental section showed subchondral cysts of the patella and femoral condyle in rats in which the knees had been immobilized with an internal plastic splint. The progress of change from cartilage fibrillation to subchondral vascular reaction to actual cyst formation was shown. A pathogenic sequence, based on the observation, was presented in an accompanying text.

The acetabular cysts and the experimental cysts are similar in several respects, and it is proposed that each has the common precipitating factor of pressure trauma in a limited area.

**Fractures of the Femoral Condyle Treated with a Femoral Condyle Blade Plate.** Dr. Robert B. Elliott[19] described the design and mechanical and physiological features of the new femoral-condyle blade plate and discussed the method of insertion.

Eight representative cases of a series of thirty fractures of the femoral condyle were exhibited. Data showed equal distribution of right and left femora and of male and female

16. 85 Jefferson Street, Hartford 14, Connecticut.
17. 248 South 21st Street, Philadelphia 3, Pennsylvania.
18. 2201 Avenue "D", Galveston, Texas.
19. 217-219 Medical Arts Building, Houston 2, Texas.

patients. Two-thirds of the fractures were caused by automobile accidents and the balance by other accidents, including falls. The age distribution was from nineteen to eighty-five years. All cases were consecutive and were followed until final healing and maximum recovery; all fractures healed, and there was no non-union. In three cases of pre-existing non-union, the result of other methods, the femoral plate was used and bone-grafting done; all fractures healed without difficulty or complications. At the time of last follow-up the average range of motion at the knee was 112 degrees in all patients including those with non-union of fracture. In those patients with fresh fracture only, the average range of total motion was 121 degrees. Only one patient, in this series, who had a normal knee prior to fracture failed to obtain 90 degrees or better of flexion of the knee. Of the thirty cases in the series, ten patients (one-third) obtained essentially normal knees with full extension and full flexion; this is a distinct improvement over the results reported in the literature.

Dr. Elliott's objective was to design an internal-fixation device of sufficient strength and mechanical efficiency to stabilize the fracture fragments properly. This permitted early motion of the knee, thereby eliminating, to a certain extent, stiffening of the knee and surrounding tissues with casts, traction, and other current methods of treatment. Dr. Elliott said that this objective was achieved, as proved by results of his study.

**Orthopaedic Pathology.** Dr. William F. Enneking[20] correlated the histopathological findings and the clinical results in cases of gout, secondary hyperparathyroidism, congenital syphilitic epiphysitis, aseptic necrosis of the femoral head in childhood, and metastatic carcinoma of the distal phalanx.

**Cineradiography.** Dr. J. William Fielding[21] and Mr. Robert W. Carlin discussed the dangers of overradiation and described how image intensification can overcome this danger and make the production of fluoroscopic motion pictures and other allied forms of investigation practical and safe. The physical set-up for production of such motion pictures was diagrammatically indicated.

A continuous moving picture, lasting about six minutes, showed motions of various joints as seen in the cineradiogram. The authors said that these motion pictures are a permanent record of dynamic body function in health and disease and are valuable as a teaching aid.

**A Skin Marking Pen.** Dr. J. William Fielding[21] and Dr. Hudson J. Wilson, Jr., displayed a felt nib utility marking pen, which they have found extremely useful in orthopaedic surgery for marking skin, plaster, and roentgenograms and which they are now using chiefly as skin markers to indicate injection sites, skin incisions, and surface anatomy. The pens write with light pressure, and the ink is sterile and, after drying, resistant to removal by standard preps and washing. If necessary, the ink can be easily removed with benzine or ether. These pens are commercially available and can be conveniently carried in the same manner as a fountain pen.

**Hand Injuries.** Dr. Richard H. Fisher[22] showed Kodachrome prints of severe injuries to the hand. These prints were made prior to and following early definitive surgical treatment. The importance of carrying out adequate initial surgery, following the atraumatic technique emphasized by Dr. Bunnell, was stressed.

Included among the cases was one showing a new procedure for reconstructing the thumb by utilizing a flap of skin along the radial side of the hand. This flap was tubed about a bone graft from the iliac crest. During this procedure, the web space was deepened by dividing a portion of the adductor muscle. The web space was filled with a thick split-thickness skin graft. This procedure has the advantage of producing skin with sensation and gives a better cosmetic and functional result than the abdominal-flap reconstruction. This new procedure is recommended when there is a normal index finger (which should not be sacrificed for a thumb if at all possible) and when a sufficient segment of metacarpal remains.

Another case illustrated that an amputated finger tip can be effectively covered by using a triangular pedicle-flap graft from either side of the pulp. These triangular flaps actually represent the "dog ears" that are usually removed. However, by preserving some of the pulp attachment, the flaps can be sutured over the tip of the finger. This obviates the need of a cross-finger or a palmar flap graft, which does not provide as good sensation as the procedure described.

**Experimental Arthroplasty of the Knee.** Dr. Joseph L. Fleming[23], Dr. Christopher Glenney, Dr. Jerome Stroot, and Dr. Victor Zackey made a study of experimental arthroplasty in the knee of dogs to determine the results after using various types of interposing

20. University of Mississippi Medical Center, Jackson, Mississippi.
21. 105 East 65th Street, New York 21, N. Y.
22. Lewis-Gale Hospital, Roanoke, Virginia.
23. Henry Ford Hospital, Detroit 2, Michigan.

membranes. Forty-nine operations were done, of which nineteen had to be excluded for various reasons—usually infection or death. Thirty animals were available for follow-up at intervals of from twenty-one to thirty-six weeks after surgery.

In eight control animals all the cartilage and menisci were removed from the knee joint and patellectomy carried out. An average follow-up of twenty-four weeks showed a successful clinical result of 25 per cent in these animals. Teflon placed with titanium staples on the tibia and femur or on the femur alone gave a good or excellent result in 67 per cent of the experiments. None of the three procedures with nylon sheet was satisfactory and only one of three with mylar sheet was satisfactory. Only one of three procedures with stainless-steel mesh gave a satisfactory result. Skin arthroplasty was done on three dogs and fascial arthroplasty on four; all of these dogs had to be excluded because of infection.

The following observations were made:

1. All interposing membranes, including even the steel mesh, wore through at the weight-bearing area.

2. The control animals had the best formation of fibrocartilage and very little fibrocartilage was seen in any of the other animals on which arthroplasty was done.

3. In the fabric arthroplasties, the fabric became covered with and incorporated into the healing membrane.

4. Sheet material such as nylon or mylar remained uncovered within the joint and became torn and loose.

5. The best results were obtained in fabric arthroplasty.

6. Good or excellent results were highly correlated with the resultant stability of the joint.

7. Severe degenerative arthritis developed in all joints regardless of the result.

A result was classified as excellent when a dog had an almost normal range of motion with minimum flexion deformity and ran and jumped on the knee operated on with an efficiency equal in performance to his unoperated knee.

**Flexion and Extension X-Rays of the Lumbosacral Spine.** Dr. Lee T. Ford[24] showed roentgenograms of the lumbosacral spine with particular reference to lateral roentgenograms made first with the patient standing in full flexion, and then in full extension of the spine. (This bending technique was first described by Knutsson in 1944.) Such a method may demonstrate abnormal mobility of one vertebra upon another, and this instability usually indicates a degeneration of the disc or disc unit between these vertebrae. The lateral roentgenogram made in full flexion may also help demonstrate an isthmus defect in spondyloschisis (spondylolysis) or in spondylolisthesis.

Such roentgenographic studies were made in the office; 567 patients were routinely examined for low-back pain and the roentgenograms were analyzed for the exhibit. One hundred and forty (26.5 per cent) roentgenograms showed evidence of abnormal mobility in flexion or extension in the lumbosacral spine either by excessive mobility or by an abnormal shift anteriorly in flexion, anteriorly or posteriorly in extension of one vertebra upon the other. Other abnormalities found when interpreting all the roentgenograms made were reviewed and analyzed in the exhibit. These included, in each instance, an anteroposterior, lateral, and right and left posterior oblique views, as well as the two lateral roentgenograms made in full flexion and extension.

Color transparencies were used to demonstrate the positioning of the patient for these roentgenographic views, and representative roentgenograms were shown to illustrate the various types of abnormal mobility.

The importance of this type of roentgenogram is that it may reveal the only abnormal findings in a situation where routine roentgenograms are negative. The presence of abnormal mobility between vertebrae usually indicates disc degeneration, although, of course, there can be other causes.

**Some Anatomic and Histologic Studies on New Born Congenital Equinovarus and Calcaneovalgus Feet and Normal Feet.** Dr. Joseph A. Freiberg[25].

**Clinical Applications of the S.A.C.H. Foot.** Dr. Everett J. Gordon[26] displayed several models of a S.A.C.H. foot with longitudinal sections that showed the component parts and manufacture of the unit. The models revealed the wooden keel covered by laminations of varying density and durometers of neoprene, covered by a felt belting which is attached to the keel by two wooden screws to prevent the keel from extruding through the underlying rubber base. The heel consists of multiple layers of laminated neoprene or cellular rubber of varying density. The foot itself is attached to the shank by a single stud bolt, dowling, and glue. A revolving wheel showed the effect of compression on the S.A.C.H. foot with heel contact throughout the walking phase. A method of study by roentgenograms of de-

24. 4952 Maryland Avenue, St. Louis 8, Missouri.
25. 2939 Vernon Place, Cincinnati 19, Ohio
26. 2007 Eye Street, N.W., Washington 6, D. C.

fects of manufacture was also demonstrated. Models showed the use of the S.A.C.H. foot with various types of lower-extremity prostheses.

The advantages of the S.A.C.H. foot are principally the less shocking heel strikes of the artificial limb, resulting in a smoother gait with less irritation of the stump. Some lateral motion is permitted by the flexible heel, improving gait on rough, uneven terrain. Maintenance of the entire prosthesis is facilitated by a S.A.C.H. foot which eliminates the need of frequent replacement of rubber bumpers and recurrent loosening of the ankle at its attachment to the shank which causes undesirable rotation stress upon the stump. In addition, the S.A.C.H. foot has a more pleasing cosmetic appearance and functions without noise.

The S.A.C.H. foot has now been universally accepted for all types of lower-extremity amputations and is rapidly replacing the conventional wooden foot as a standard component for lower-extremity prostheses.

**A Posterior Approach to the Knee Joint.** Dr. Nicholas R. Greville [27] and Dr. V. W. Stewart described a simple and adequate exposure of the posterior compartment and the intercondylar-notch area of the knee joint. From the medial side the deep fascia was incised anterior to the medial hamstrings, with the knee flexed at an angle of 30 degrees, and the medial head of the gastrocnemius was exposed. This was divided transversely near its origin above the femoral condyle and turned laterally, protecting the popliteal vessels and nerve. The capsule of the knee was exposed and could be incised over the posteromedial compartment or the intercondylar notch.

From the lateral side, the lateral head of the gastrocnemius was exposed after the tendon of the biceps femoris and the common peroneal nerve had been dissected and retracted posteriorly. The gastrocnemius was dealt with in the same way on this side as medially, and the posterolateral compartment was exposed.

Dissections to show these approaches and also to show the extensive dissection and limited exposure of other posterior approaches to the knee joint were demonstrated, with colored slides made during the dissections to show the steps.

**End Results from Lower Lumbar-Spine Vertebral Body Fusions for the Disc Syndromes, Carried Out by an Abdominal Extraperitoneal Approach.** Dr. Paul H. Harmon [28] presented narrative, pictorial, and diagrammatic descriptions of the operative technique for near-total excision and bone-graft replacement of the lower three lumbar intervertebral discs, which featured: (1) an extraperitoneal approach; (2) a fixed and stable operative field, obtained by spiked retractors driven into the vertebral bodies; (3) excision of the disc and cortical vertebral plates under full visual control; and (4) an immediate stabilization of the vertebrae by bone grafts transversely impacted into the excisional defect. The improved and modified technique has been in use for two years, and 120 patients were operated on. The total experience with this general type of operation has been with more than 200 procedures extending over the last eleven years. Dr. Harmon showed the special instruments that facilitate the operation: retractors, special stripping instruments, bone-graft holders, and impactors.

Statistics of ninety recent cases and ten-year end results from an earlier series of thirty-nine cases were presented. These data were analyzed according to the patients' statements of relief from radicular pain and lumbago and according to roentgenographic results from motion roentgenograms and short-focal-spot magnification studies to ascertain osseous union. All patients had prompt relief from radicular pain with quick relief from lumbago in some cases and slower (two to four months) relief from lumbago in other cases. The results in all cases improved with the passage of time and there have been, for practical purposes, no recurrences. The very few so-called recurrences were failures to assess completely the pathology when too much reliance was placed on myelographic defects in the early cases. Sixty per cent of the patients returned to work within three months and an additional 28 per cent by six months; most of them (95 per cent) returned to their customary occupations. Half of the patients were workers in heavy industry—stevedores, steel-mill workers, truckmen, and telephone linemen. Almost all patients, once back at work, were free of complaints relating to the lumbar spine. The results have been satisfactory for both patient and surgeon. Fears that an irretrievable annulus fragment within the spinal canal would be the cause of continued pain have been shown in our experience to be groundless. There were no instances of undesirable operative sequelae, either neural or vascular.

Roentgenographic studies indicated 82.8 per cent of osseous union (calculated on the basis of total vertebral spaces operated on) in patients in the 1948 to 1949 series and 98.8 per cent in those in the 1957 to 1958 series. It is possible that a very few of the latter will deteriorate. Patients showing incomplete or fibrous union were also relieved of symptoms. The magnified roentgenograms of four illustrative ten-year end results and of eight representative disc and instability conditions were shown.

An important phase of this work was a study of the anatomy and variations of the

27. Emory University School of Medicine, Atlanta 3, Georgia.
28. 2425 Geary Boulevard, San Francisco 15, California.

vena cava and left common iliac venous channels from observations at operation. The veins are practically the only hazard that deserves special attention. Drawings and data were presented on: (1) the cephalad and caudad shift of the vena cava bifurcation relative to the fourth and fifth lumbar vertebral bodies; (2) the method of dealing with the large medially placed left common iliac vein, encountered in 30 per cent of the spines in the anterior approach to the fifth lumbar disc; (3) the variations in placement and management of the great veins and their connections as applied to the approach to the fourth and third lumbar disc; (4) several other venous-variation patterns; and (5) the general plan of all the veins of the area. This material will aid those who wish to do this type of operation.

**Paralytic Scoliosis.** Dr. Paul H. Harrington [29].

**Instruments for Performing a Cervical Interbody Fusion (Cloward) by the Anterior Route.** Dr. Norman M. Harris [30] and Dr. Anthony J. Smith.

**Fibrous Dysplasia.** Dr. W. H. Harris [31], Dr. P. H. Benedict, Dr. H. R. Dudley, and Dr. Roy Barry reviewed the entire experience at the Massachusetts General Hospital with regard to fibrous dysplasia. Follow-up examination of all available patients was carried out. The outstanding findings were: the biological spectrum of the manifestation of the disease is much greater than was previously appreciated. Roentgenographic diagnosis without histological confirmation is treacherous, except for certain specific roentgenographic signs. Progression of the disease can occur after puberty as well as before. The majority of fractures heal well with conservative treatment, but judicious operative intervention can be helpful. Autogenous grafts appear to be superior to other forms. There was a 25 percentile of error in diagnosis in this study. There were no proved cases of malignant tumor in which heavy radiation had not been given at least twenty years previously.

**Operative and Non-operative Management of Fractures of the Pelvis.** Dr. Earl P. Holt, Jr. [32], Dr. Walter R. Johnson, and Dr. Sergio Brillantes presented ten selected cases of fracture or fracture-dislocation of the pelvis which were illustrated by eight-by-ten-inch transparencies. Three or four transparencies, with accompanying legends, were used to illustrate each case.

It was demonstrated that quite severe fractures, such as the Malgaigne fracture, can be handled by conventional manipulative or traction methods or both, especially if adequate anesthesia is available. A five-year follow-up of an unusual open fracture-dislocation of the innominate bone in a five-year-old child was presented. There was also a report of a non-union of a fracture of the sacrum in a young adult that eventually required bone-grafting.

Three cases demonstrated the newer approach toward handling disruptions of the acetabulum by open operation and pin fixation across the ilio-ischial zone of the fracture. One of these patients was followed five years and had an excellent clinical result, despite the fact that the hip had to be dislocated before exact reduction could be accomplished.

**Simple Night Splint for Tibial Rotation.** Dr. Rex J. Howard [33] had planned to present an exhibit which consisted of shoes with a chain attached either to the heel or to the toe for treatment of internal and external rotation of the tibia.

Dr. Howard said that this splint has the advantages of being less expensive, more easily applied, better tolerated by the children, and not so easily tangled in covering as the Denis Browne splint.

**Anterior Spinal Fusion.** Dr. A. W. Humphries [34] and Dr. W. A. Hawk reported on experiments with animals and a preliminary study on a pilot group of patients in regard to a new method of anterior interbody spine fusion. The technique is based on the premise that several criteria are constant for osseous union regardless of the bones to be fused. These criteria are: adequate blood supply, adequate bone contact, the absence of distraction, and immobilization until bone union is firm. All four of these are difficult to attain by fusion of the lumbar vertebrae done between posterior elements. However, if the bodies of the vertebrae are approached anteriorly, when all of the disc material is removed and the opposing cortical plates of the adjacent vertebrae are removed, an adequate blood supply is attained. Packing of this space with ground cancellous bone as a graft permits bone contact over a large area. The application of a specially designed plate to be affixed to the anterior surfaces of the two adjacent vertebral bodies by screws permits the attainment of immobilization and prevents distraction.

29. 4520 Rossmoyne Boulevard, Houston 6, Texas.
30. 320 West Central, Coos Bay, Oregon.
31. Massachusetts General Hospital, Boston 14, Massachusetts.
32. 3720 Washington Boulevard, St. Louis 8, Missouri.
33. 930 Fifth Avenue, Fort Worth 4, Texas.
34. Cleveland Clinic, 2020 East 93rd Street, Cleveland 6, Ohio.

The use of the immobilizing plate in animals resulted in histologically proved bone healing in all instances, whereas synarthrosis developed in those dogs in which the fixative device was not used.

A preliminary group of seventeen people having spine fusions between the fourth and fifth lumbar vertebrae, the fifth lumbar and the first sacral vertebrae, and two-level fusions from the fourth lumbar to the first sacral vertebra were reviewed, the earliest having been followed for a period of one and one-half years.

In no instance had the plate broken or changed position, and rarefaction did not develop along any screw tract, indicating motion. By the few criteria available—static roentgenograms, stress roentgenograms, and clinical symptoms—all patients receiving interbody spine fusion by this technique appear to have attained a stage of bone union compatible with the length of time that they have been followed.

**1. Foot Support and Exercises, 2. Leg Splint, 3. Improved X-Ray Technique for Hip Fractures.** Dr. Frederic W. Ilfeld[35] exhibited three gadgets: a metal foot support and exerciser, an improved Thomas leg splint, and a simple plate holder for lateral roentgenograms of the hip.

The foot support consists of a metal plate held by an adjustable screen-door spring and fastened to the Thomas splint by lateral clamps. The foot is supported at 90 degrees of flexion and can be exercised in plantar flexion against the resistance of the screen-door spring. This active, resistant exercise maintains muscle tone and discourages thrombophlebitis.

The modified half-ring Thomas leg splint has an adjustable right-angle offset to permit more room at the groin. The offset is reversible to permit use on either the right or left

A metal book end and paper clamp, found in any stationery store, are used to hold the leg. It makes for greater comfort in balanced traction.
cassette for a lateral roentgenogram of the hip during surgery. This method of holding the film eliminates exposure of operating-room personnel to radiation, abolishes frog-legging of the hip, and gives an accurate lateral roentgenogram. The method is applicable to an ordinary operating table or fracture table. The uninvolved leg is elevated on a gynecological stirrup or abducted on the fracture table. This permits placement of the portable x-ray machine. The x-ray tube is directed toward the groin. The rays transect the neck of the femur at a right angle which is about 35 degrees lateral to the femoral shaft. The x-ray cassette is placed in a sterile pillow case and held next to the ilium with the sterile metal book end. The cassette is further stabilized by clamping the sterile pillow case to the sterile drapes with the sterile paper clamp. The leg is held in 15 degrees of internal rotation with a sandbag in a sterile pillow case. The anteroposterior view is obtained in the usual way with a cassette box under the pelvis.

**Bone Cysts.** Dr. Lent C. Johnson[36] and Dr. Robert G. Kindred.

**The Cerebral Palsy Training Center of Fall River.** Dr. William E. Kenney[37] discussed the activities of the Cerebral Palsy Training Center of Fall River, Massachusetts. Most of the various modalities of treatment in use at the Training Center were illustrated by posters that presented the aims and the progressive steps by which the aims are accomplished. Also shown were descriptive posters of: physical therapy, occupational therapy, didactic teaching, orthotics, speech and hearing training, socialization with volunteer help, and monthly consultation day. One poster summarized the corporate structure and financial history of the organization. In addition, replicas, in scale, of each room and the specialized equipment for that room were displayed.

The salient points of the exhibit were:

1. A small city (pop. 100,000) can develop and support a training center with comprehensive and conservative management of children with cerebral palsy on an out-patient basis.

2. Such a training center can give service along several avenues, such as physical therapy, occupational therapy, speech, teaching, and orthotics.

3. Several persons of varying professional disciplines can and do work under the direction and prescription of the orthopaedist as an integral team for the benefit of the child.

4. The orthopaedist has the responsibility to direct the use of physical therapy and occupational therapy, and to prevent the abuse of these modalities.

5. A group of public-spirited citizens can form a charitable, non-profit corporation which can give services to children with cerebral palsy at a cost of $525.00 per year per child as compared with the often-heard figures of twice this amount.

35. 436 North Roxbury Drive, Beverly Hills, California.
36. Armed Forces Institute of Pathology, Washington, D. C.
37. Cerebral Palsy Training Center, 218 Calvin Street, Fall River, Massachusetts.

**Orthetic Devices for Upper Extremity Bracing.** Dr. Kenneth S. Landauer[38] and Dr. W. Kenneth Lane said that the orthetic devices shown in their exhibit were developed or adapted by some of the sixteen Regional Respiratory and Rehabilitation Centers aided by grants from The National Foundation. They do not represent all types of basic ortheses. Included in the exhibit were: a simple opponens splint with dynamic wrist and lumbrical bar, a functional arm brace, an experimental artificial muscle, and a dorsal finger-flexion unit. All devices were arranged so that they could be taken off the exhibit and tried on.

The need for better designed orthetic devices has become more and more apparent as the number of patients with severely paralyzed upper extremities has increased. As improved medical skills have saved and prolonged the lives of these catastrophically disabled patients, it has become imperative to make their lives worth saving. This means, at the very least, helping these patients to regain some measure of personal independence—to feed themselves, care for their personal needs, and pursue vocational and recreational activities. The development of orthetic devices to increase or assist function plays a large part in the concept of total rehabilitation.

**The One Hand Drill.** Dr. Lillian S. Lusskin[39] and Dr. Ralph Lusskin.

**Chemical Osteosynthesis.** Dr. Michael P. Mandarino[40] and Dr. Joseph E. Salvatore said that it has long been felt that a chemical compound could be developed, which could be poured, in liquid form, into a fracture site and produce bonding of diseased or fractured ends of bone. Research on the literature disclosed the properties of polyurethane foams in rigid form which meet the requirements for strength, immobilization, non-toxicity, adhesion and cohesion, torsional stabilization, and ease of handling required for bone surgery.

For the purpose of producing a dense, rigid, cellular foam for orthopaedic use, a prepolymer was prepared by reacting a trihydroxy resin with an excess of 2-4 diisocyanate. This formed a prepolymer, which, at the time of surgery, was again reacted with water and a catalyst. The first reaction after the isocyanate addition is the formation of the urethane linkage at the hydroxyl position. Next there is the reaction of the active urethane hydrogen H+ by the diisocyanate. The $CO_2$ release is effected by water or the large number of carboxyl groups or both. As the reaction proceeds, the plastic mass becomes increasingly tough, and the liberated $CO_2$ causes it to swell like dough.

In bone surgery the reaction mixture is poured into the affected area or parts before polymerization and cross-linking reactions begin. It is apparent that the added prepolymer is an active material and that it therefore bonds to the surfaces to be held, bridged, filled, or strengthened. This real bonding consists of more than a glued joint for the isocyanate contained in the prepolymer, and the catalyst mixture is so reactive that it finds chemical groups which are not only on but also a part of the adjacent surfaces with which it reacts. The polyurethane, in and during its formation, becomes an intimate part of the bone.

The use of ostamer is best restricted to those anatomical regions where adequate hemostasis, by tourniquet or other established techniques, may be secured. Sufficient fixation for wound closure occurs in twenty to thirty minutes. Complete hardening requires eighteen to twenty-four hours, during which time a posterior splint may be used. After a curing time of from twenty-four to forty-eight hours, the stability of the bonded area is such that weight-bearing may be initiated. The chemical remains radiolucent.

Experiments for non-toxicity were performed using tissue culture, guinea pigs, and rats, with no contra-indicative findings.

In a typical dog experiment defects were created and the distracted cortices then bonded with ostamer. In over 80 per cent of the operations bone has had to bridge large gaps. These gaps would have certainly resulted in non-union of bone without the polyurethane bonding.

Thirty-two human beings were treated with ostamer. There were five non-unions of femora, three malignant growths of femora, two acute fractures of femora, sixteen non-unions of tibiae, one cyst of the tibia, one acute fracture of the tibia, two cysts of the humerus, and two pathological fractures. The longest follow-up in cases involving human beings was twenty-seven months and the longest follow-up in cases involving dogs, thirty-four months. The results in all cases ranged from good to excellent.

Grossly and microscopically, the polyurethane foam is slowly absorbed by the body from the site of implantation with approximately one-fourth of the original implant remaining at the end of twelve months. Pharmacological and toxicological studies are continuing.

**A Comparative Study of Spinal Fusion by the Combined Interbody and Posterior Element Method with the Hibbs Posterior Element Fusion with the H-Graft Modification.** Dr. William

38. The National Foundation, 800 Second Avenue, New York 17, N. Y.
39. 41 West 70th Street, New York 23, N. Y.
40. 210 North 15th Street, Philadelphia 2, Pennsylvania.

K. MASSIE [41] said that his study was partly based on preoperative nucleographic findings.

Dr. Massie also said that the method used of evaluating results in low-back pain is partially responsible for the confusing variance in conclusions.

In this series each patient is rated as either excellent or not excellent according to three categories: symptomatic, functional, and roentgenographic. An excellent rating indicates normal response symptomatically and functionally and unquestioned fusion roentgenographically. Complete obliteration of the articular facets in the oblique view has proved to be far more critical than forced-extension and lateral-bend views.

The treatment of low-back pain has as its objective symptomatic relief compatible with the normal activities for each specific patient. For this reason treatment varies widely with age, sex, and occupation. The identical pathological condition in three different patients, each forty-five years old, was treated differently. A housewife would be treated conservatively, a male white-collar worker would have simple disc excision, and a laborer would have disc excision and interbody-posterior-element fusion. These three patients would require three different forms of treatment. Ninety per cent of our patients would be treated conservatively, and 4 per cent would have simple disc excision (not discussed in this report). Six per cent would have disc excision and fusion, which is performed when the age and occupation of the patient demand a functionally normal back for heavy work. The objective of this operation is stabilization, since disc degeneration results primarily in intervertebral instability. Instability of the posterior element is relatively unimportant because this element bears little weight. A method of fusion that includes all elements of motion in the intervertebral space seems logical.

The advocated method of fusion is as follows:

1. Removal of an oblique dowel, ten-sixteenths of an inch, through the posterior approach (Wiltberger technique) from between the vertebral bodies. The maximum amount of disc material is excised.

2. Impaction of cancellous autogenous bone into the space held in place with a cancellous dowel, one and one-sixteenth inches, containing two cortical ends*.

3. Decortication of the lamina of the contralateral side and excision of the articular facet, and application of cancellous chips.

4. Release of the interspinous spreader allowing the spinous processes to approximate slightly (they are still held apart by the interbody graft which eliminates most of the intervertebral motion).

5. Insertion of a combined cancellous and cortical H-graft in the interspinous space.

6. Application of a No. 20 wire loop around the approximated spinous processes, preventing any possible separation in forced flexion.

The extent of the fusion is as important as the method of fusion, that is, if three disc spaces are degenerated, solid fusion of one or even two spaces will not attain the objective. Therefore, to operate on this all-or-none basis, the surgeon must be certain of the degree and extent of the instability. Nucleography seems ideally suited to provide the required information because: there are no false-positive findings; a normal outline indicates a normal disc; the incidence of partially degenerated discs is far higher than is shown by simple roentgenograms or myelograms; a normal fifth lumbar disc is rare in the presence of a protruding fourth lumbar disc; duplication of symptomatology by injection of the disc is informative; and a complete survey of existing disease is most reassuring when a decision as to treatment is at stake.

In general, there was unquestioned fusion in 76 per cent at the levels of the fifth lumbar and first sacral vertebrae and 60 per cent at the levels of the fourth lumbar and first sacral vertebrae by the combined methods compared with 42 per cent and 25 per cent, respectively, at the same levels by the posterior-element method alone. In the combined-fusion group twenty-one of thirty patients returned to their original occupations as compared with thirteen of thirty-six in the posterior-element-fusion group. Sixty per cent of the patients in both groups were heavy laborers. Thirty-three per cent of the patients in the combined group were normal symptomatically, functionally, and roentgenographically as compared with 13 per cent in the posterior-element group.

In summary, Dr. Massie said that:

1. To compare results of various procedures by one observer or various procedures by various observers only, the excellent results (return to nomal) symptomatically, functionally, and roentgenographically should be considered.

2. An accurate complete diagnosis directs any successful treatment. Discography demonstrates a pathological condition long before it becomes symptomatic, and has been used preoperatively to evaluate the various levels.

3. Interbody or posterior-element fusion alone seems insufficient. The combined interbody and posterior-element fusion seems after a two-year trial to result rather constantly in solid fusion without the need for bracing or prolonged protection after operation.

4. Complete disc excision alone often gives acceptable results for occupations which ex-

41. 288 South Limestone Street, Lexington 4, Kentucky.

* More recently, homogenous cancellous chip or cortical dowels are used, thus obviating a donor-site incision.

clude moderate or heavy labor. However, I have never seen an excellent result from this treatment. Nevertheless, to be replaced by a more formidable stabilization procedure, the results must be consistently superior.

5. If the real objective—stability—can be attained while permitting free mobility of the back and extremities to prevent nerve-root adhesions, then in the patient whose age, sex, and occupation require continued moderate to severe activity, a combined posterior-element-interbody fusion seems the procedure of choice.

6. In spondylolisthesis the posterior elements are usually partially removed so that the advocated fusion cannot be accomplished. In these patients it has seemed best to combine the interbody graft with bilateral grafts over the transverse processes, as described by Watkins. In these patients a short, single leg spica to the knee has been used, as suggested by Ford.

**Hoke Traction in the Treatment of Femoral-Shaft Fractures in Children.** Dr. John R. Moore [42], Dr. A. F. Seifer, Dr. J. W. Lachman, and Dr. H. H. Steel.

**Multiple Myeloma.** Dr. R. A. Murray [43], Dr. W. N. Powell, Dr. R. D. Haines, Dr. A. W. Sommer, and Dr. W. A. Ross summarized their experience with eighty-five proved cases of multiple myeloma, from the viewpoint of the orthopaedic surgeon, internist, roentgenologist, and clinical pathologist.

The disease occurred in fifty-four men and thirty-one women; the majority of the patients were between forty and seventy years of age. Skeletal pain was the most frequent symptom, with twenty-two of the patients having symptoms not unlike those associated with lesions of the intervertebral disc. Seventy-six per cent of the patients, on initial examination, had abnormal roentgenographic findings. Albuminuria, anemia, and high sedimentation rate were significant laboratory findings, accounted for by abnormal protein metabolism. Electrophoresis was employed in the last fifteen patients seen and was found to be a valuable diagnostic aid. When serum and urine were combined for this study accuracy was increased. Although multiple myeloma is universally fatal, we believe the treatment we have used may relieve discomfort and promote a longer life.

The authors also described medical management with urethane, irradiation, and steriods, and orthopaedic measures.

**A Clinical Study of Demineralizing Bone Disease.** Dr. James A. Nicholas [44], Dr. Philip D. Wilson, and Dr. Robert Freiberger presented the data from a study of the pertinent clinical, roentgenographic, and laboratory characteristics of patients admitted to the Hospital for Special Surgery since 1950 because of compression fractures and demineralizing bone disease.

Fifty-seven patients with adequate cause for trauma, a known malignant condition at the time of admission, or inadequate work-up were discarded, leaving 105 patients who comprised this series. The exhibit illustrated the essential methods by which diagnosis was established, as well as the unusual characteristics of various diseases encountered in the differential diagnosis.

Emphasis was placed on conditions other than osteoporosis which may produce demineralization. Among the interesting cases presented in the exhibit were patients with hyperparathyroidism, polycythemia vera, myasthenia gravis, Waldenström's macroglobulinemia, Milkman's disease, and ankylosing spondylitis. A severely demineralized woman, forty-three years old, with post-menopausal osteoporosis was also presented, as were patients with myeloma, metastatic carcinoma, and malignant lymphoma.

Roentgenographic criteria for demineralization were discussed, as well as the diagnostic scheme utilized in order to study the patient. Those diseases on which an early diagnosis would result in cure were illustrated by roentgenograms made before and after treatment or operation.

The exhibit emphasized the difficulties of diagnosis as well as some of the important factors which may lead to an early accurate diagnosis.

Osteoporosis can be confused with many other conditions, and it is suggested that all patients under fifty-five with compression fracture and inadequate trauma should be hospitalized and thoroughly studied. They should have direct biopsy of sternal or iliac marrow as well as direct biopsy of the lesion where accessible, and twenty-four-hour urinary calcium on varying intake, as part of their study.

**Cerebral Palsy: A Basic Approach to Successful Management.** Dr. Winthrop M. Phelps [45] described the activities of the Children's Rehabilitation Institute for Cerebral Palsy, Reisterstown, Maryland, in connection with the total problem of cerebral palsy.

The program there comprises four separate fields: (1) diagnosis and evaluation of patients by the medical team; (2) treatment of the cerebral palsied patients on a residential basis, including not only the physical problems but also intensive special education; (3) intensive

42. Temple University Hospital, Philadelphia 40, Pennsylvania.
43. Scott and White Clinic, Temple, Texas.
44. 110 East 87th Street, New York 28, N. Y.
45. 3038 St. Paul Street, Baltimore 18, Maryland.

training of qualified doctors, physical therapists, and occupational therapists in the methods of treatment—physical therapy, occupational therapy, speech therapy, as well as surgery and drug therapy; and (4) an extensive research program into the effectiveness of various types of drugs. The evidences of improvement are recorded by graphs of improvement in all of the fields of therapy.

**The Determination of Fracture Healing by Measurement of Sound Velocity across the Fracture Site.** Dr. Irwin M. Siegel[46], Dr. G. T. Anast, and Mr. T. Fields described a new and more objective method of analyzing the degree of healing of a fracture.

At present the state of healing of a fracture can only be determined by subjective examination such as that afforded by roentgenograms and a clinical appraisal of the broken bone. These methods are subject to error and, as is often the case with subjective examination, the results obtained may be equivocal.

The new technique exhibited measures the sound velocity across a fracture site and compares it with that of the opposite, normal extremity. The apparatus utilized is similar to that employed by the concrete industry for determining the quality and internal integrity of concrete forms.

The method consisted in sending a short-duration, sonic pulse through a leg by a transmitting transducer and measuring the time for this pulse to reach a receiving transducer. A series of litter-matched rabbits was examined by comparing serial readings taken across a healing tibial-fracture site with similar readings taken concurrently on the contralateral, non-fractured leg. Sound-velocity examinations were also made on human tibial fractures at various stages during healing. Fractured limbs were examined through a cast window or with a posterior plaster shell in place, and the opposite, normal member was used as a control.

Of sixteen rabbits examined, twelve fractured tibiae healed without complication. Although sound velocity in the fractured legs was reduced immediately after fracture and during healing, a normal velocity (as compared with that of the opposite, intact extremity) was always obtained at the time of clinical union. Osteomyelitis developed in one animal at the fracture site. This delayed but did not prevent union, the sound velocity returning to normal when the bone was clinically solid even though minimal purulent drainage was present. Three fractures eventuated in non-union. In each of these gross motion was present at the site of fracture, and sound velocity did not return to normal, remaining between 50 and 80 per cent of normal for as long as fourteen days after the time union was obtained in the slowest of the healing fractures.

Normal values were determined on a group of intact human tibiae and were reproducible within plus or minus 5 per cent. The average velocity recorded over a fifteen-centimeter path was 3,481 meters per second. The effect of osteoporosis on sound velocity was determined by examining a series of eleven paraplegic limbs, sound-velocity readings of which were noted to overlap the normal range.

In studying twenty-six patients with tibial fractures, sound velocity was slowed from 4 to 40 per cent of normal. The velocity of sound appeared to be related to the degree of fracture union. It was observed that human fractures at various healing times had sound-velocity readings below those of the normal contralateral tibia, that fractures when united and bearing weight had normal sound velocity, and that established non-unions showed below-normal readings which did not significantly change on several examinations at biweekly intervals.

Sound-velocity measurements may prove a useful adjunct to roentgenographic and clinical examination of fractures.

**Iliac Osteotomy.** Dr. William Snell[47] described the surgical technique and clinical advantages of this procedure, performed on children with exstrophy of the urinary bladder. In conjunction with conventional urological repair, bilateral iliac osteotomy directed laterally and parallel to the sacroiliac joints: (1) simplifies urological rehabilitation, (2) corrects the external rotation of the hips, (3) improves gait, and (4) allows approximation of the pubic symphysis.

**The Split Diamond Nail.** Dr. Dana M. Street[48] and Dr. David G. Vesely described the retrograde insertion of the split diamond nail in the femur and illustrated its use in fractures of the lower third of the femur, including supracondylar and condylar fractures. They also showed the use of the nail in actual prepared bones—four femora, two tibiae, two humeri, one tibia with two fractures, and one humerus with two fractures.

The nail is of two types: a terminal split nail in which the distal one-third of the nail is split longitudinally with the split ends diverging like a fork; the second or central split nail is split a major portion of its length and bows outward at the center, the distal ends again converging and in approximation. The terminal split nail is of particular value in fractures near the ends of long bones where the diverging points obtain a more solid hold in the short

46. Veterans Administration Hospital, Hines, Illinois.
47. University of Oregon Medical School, Portland 1, Oregon.
48. University of Arkansas Medical Center, Little Rock, Arkansas.

fragments. It is particularly useful for fractures of the distal part of the femur, proximal or distal part of the tibia, and the proximal end of the humerus. The center split nail is well adapted to the mid-shaft fractures of the humerus where the tapered canal precludes solid fixation with conventional nails. The uses of the nails in the different bones were illustrated by case reports and mounted specimens of bone.

**Fractures of Os Calcis. Open Reduction and Primary and Secondary Fusions.** Dr. Homer H. Stryker[49] and Dr. Harold J. Meiers.

**Audio-Visual for the Patient.** Dr. Fred L. Stuttle[50] discussed the method he used to describe to the patient the formation and normal function of various parts of the body, and in many common situations, the patient's abnormality. The essential purpose of this method is to educate the patient on the subject matter pertinent to his particular interest, and to allow the doctor more time and opportunity to go into detail about the abnormality in regard to the patient's own particular problem.

This method of education is accomplished by thirty-five-millimeter slides, which would vary according to the choice of the individual doctor, and a tape discussion of the slides which again would be a personal expression in the doctor's own words and voice. The slides are shown on a semiautomatic projector which preheats the slides to remain in focus and the slides advance by a trigger functioning by a passage of soundless tape to the continuing tape discussion. The projector may be set up by unskilled help and will run itself to thirty-six slides.

The method represents an effort to develop the possibilities of education of the patient. The patient can hardly ever be taught too much about his condition to procure his full cooperation; partial or slight knowledge is demoralizing.

Not the least advantage of this method is that it saves time for the physician, since both he and associated personnel are relieved of extended and prolonged explanations.

**Posterolateral Fusion of the Lumbosacral Spine.** Dr. George Truchly[51] and Dr. Walter A. L. Thompson showed a modification of the posterolateral fusion of the lumbosacral spine. This operation was originally regarded as a salvage procedure reserved for patients with nonunion after multiple attempts at lumbosacral fusion. The favorable results were so impressive that this operation is now used primarily whenever fusion of the lumbosacral spine is indicated. The authors' experience with this procedure has been limited to thirty-nine patients who were operated on because of a primary unstable spine, spondylolisthesis, or unstable spine after laminectomy.

The technique was illustrated by eight drawings and nine color transparencies and can be summarized as follows: a curved skin incision is made from the lateral iliac crest to a point about two inches below the posterosuperior iliac spine, one inch lateral to the mid-line. The lumbodorsal fascia is incised along the lateral border of the sacrospinalis, and the transverse processes of the fourth and fifth lumbar vertebrae are palpated through this incision—the interval between the quadratus lumborum and sacrospinalis thus being established. The sacrospinalis origin on the posterior crest of the ilium is detached, and muscle and ligamentous attachments are dissected from the posterior aspects of the transverse processes and lateral aspects of the superior articular processes of the fourth and fifth lumbar vertebrae, as well as the lamina of the sacrum. These are fishscaled with a gouge. The graft material is obtained from the posterior iliac crest through the same incision, seven to ten long strips of bone being usually used. The graft material is packed in the interval between the sacrospinalis and the posterior aspects of the transverse processes of the fourth lumbar vertebra, fifth lumbar vertebra, and the sacral lamina. It reaches as far medially as the facets. Closure is obtained by suturing the sacrospinalis to the gluteus maximus; the rest of the wound is closed in layers.

Postoperative care consists in six weeks of bed rest with a bedboard, followed by six months of bracing with Knight's spinal brace.

The advantages of the procedure described are: apparently much lower rate of nonunion; no need of internal fixation of the graft material; easy fitting of the graft because of flexibility of the sliver; no necessity for accurate shaping of the graft; larger surface area per mass unit of graft in contact with the blood supply; after laminectomy, hypertrophy of the graft cannot encroach upon the epidural space as can happen in posterior fusion; should exploration of the epidural space become necessary at a later date, there is no fusion plate present over the lamina to interfere with laminectomy; and location of the fusion mass close to the axis of vertebral motion lessens the mechanical stresses on the fusion area.

The disadvantages of this procedure include usually a longer operating time and a greater loss of blood.

49. 903 Edgemoor Avenue, Kalamazoo, Michigan.
50. 1200 Hamilton Boulevard, Peoria, Illinois.
51. Veterans Administration Hospital, New York 10, N. Y.

**The Vascular Beds of the Foot.** Dr. James B. Wray[52] and Dr. J. E. Markee described their method of chemically digesting away the soft tissue of a normal human foot after filling the entire vascular system with plastic.

Color transparencies which depicted the specimen in progressive stages of dissection were shown by the authors, and several conclusions regarding the vascular anatomy of the foot were presented. A photomicrograph of several arterioles, 90 micra in diameter, illustrated the detail obtained by this technique.

52. Bowman Gray School of Medicine, Winston-Salem, North Carolina.

## Correction

An error occurred in the article Transchondral Fractures (Osteochondritis Dissecans) of the Talus by Albert L. Berndt, M.D., M.Sc. (Med.), and Michael Harty, F.R.C.S., published in the September 1959 issue of The Journal.

On page 991 the legend beginning Figs. 3-A through 3-H under the cuts Figs. 3-A and 3-B reads:

Figs. 3-A through 3-H: Roentgenograms showing the four stages of transchondral fractures of the talar dome—those of the lateral margin in 3-A, 3-C, 3-E, and 3-G in the left column and those of the medial margin in 3-B, 3-D, 3-F, and 3-H in the right column. In Figure 3-H the displaced chip is not seen clearly, but the lateral view of the same fracture (Fig. 15-B) shows it to occupy the anterior compartment of the ankle.

The legend should read:

Figs. 3-A through 3-H: Roentgenograms showing the four stages of transchondral fractures of the talar dome—those of the lateral margin in Figs. 3-A, 3-B, 3-C, and 3-D and those of the medial margin in Figs. 3-E, 3-F, 3-G, and 3-H. In Fig. 3-H the displaced chip is not seen clearly, but the lateral view of the same fracture (Fig. 15-B) shows it to occupy the anterior compartment of the ankle.

**RALPH K. GHORMLEY, M.D.**

**1893—1959**

The *curriculum vitae* of Ralph Ghormley is a long and distinguished one, attesting his eminent place in both American and world-wide orthopaedic surgery and the high esteem in which he was held by his associates and contemporaries.

A complete list of his honors and publications would in no way enhance this brief tribute to the friend we so greatly admire. The record of these so-called honors in orthopaedic surgery marks a path of devoted service over a period of many years. He was certified by the American Board of Orthopaedic Surgery in 1935 and later served on this board for nine years, becoming President of the board in 1951 and 1952. He served as Secretary of The American Orthopaedic Association from 1933 to 1940, and as President in 1948-1949. His services to The American Academy of Orthopaedic Surgeons are too numerous to record.

Dr. Ghormley was a member of the Children's Bureau of the United States Department of Labor; a Fellow of the American College of Surgeons; and a member of the American Medical Association; the Clinical Society of Orthopaedic Surgery, of which he was President in 1941; the American Surgical Society; the International Society of Orthopaedic Surgery and Traumatology; and finally, the Robert Jones Club, a group which has supplied many of our leaders in orthopaedic surgery. He served as Consultant in Orthopaedic Surgery to the Veterans Administration.

In reading over the list of Ralph Ghormley's slightly under 300 publications, one is

apt to be overwhelmed and then fascinated by the breadth of his experience in all aspects of orthopaedic surgery. He contributed chapters to many textbooks. In 1931, with Dr. Nathaniel Allison, Dr. Ghormley published *Diagnosis in Joint Disease: a Clinical and Pathologic Study of Arthritis*. In 1938 he was Editor of *Orthopaedic Surgery*. He repeatedly served as co-author for "Progress in Orthopaedic Surgery". His numerous articles for the most part dealt with diseases and injuries amenable to treatment by orthopaedic surgery.

However, this factual account does not give the true picture of the man which his friends would like to leave in the record for the information of future generations who will be interested in the personality and character of the men taking part in the sudden flowering of orthopaedic surgery in the years following World War I.

Ralph Ghormley graduated in medicine virtually under fire as a member of the volunteer group of medical students from Johns Hopkins who served and studied at the Johns Hopkins Base Hospital Unit in France in 1917-1918. He completed his service in the Army Medical Corps with the rank of Captain.

He returned to Johns Hopkins to take the two-year Residency in Orthopaedic Surgery. In 1920-1921 he served as an intern at the New York Hospital, returning to Johns Hopkins in 1921-1922. During 1922 he entered the practice of orthopaedic surgery with Dr. Robert Lovett in Boston. From 1923 to 1929 he was an Instructor in Orthopaedic Surgery at Harvard Medical School and was on the attending staff of the Massachusetts General Hospital.

In September 1929, Dr. Ghormley moved to Rochester, Minnesota, to join the Staff of the Mayo Clinic. He advanced through the various grades to become Professor of Orthopaedic Surgery in 1937, and in the following year became head of the section in his specialty. He retained this position until 1955 when he became Senior Consultant. He retired from practice in 1958 to live, all too briefly, in Carmel, California.

Dr. Baer, Dr. Allison, Dr. Lovett, and his seniors at the Mayo Clinic contributed notably to the breadth and variety of Ralph Ghormley's training. At the Mayo Clinic he became a superb clinician, a skillful and fearless operator, a teacher to both the local students and staff and also to the many professional visitors to that Clinic. That his professional interests were wide, including clinical and experimental research, is shown in his many professional contributions written and spoken. As a constructive idealist he labored incessantly to raise the standard of training and practice in orthopaedic surgery.

Ralph Ghormley was a tireless traveler, a willing worker, and a wise counsellor. His service on countless committees for The American Orthopaedic Association and The American Academy of Orthopaedic Surgeons, was thoughtful, productive, and definitive. It was a privilege to serve with him.

In 1957, Dr. Ghormley was honored by his former fellows in orthopaedic surgery and his colleagues in the Mayo Clinic by the establishment of the Ralph K. Ghormley Traveling Scholarship, designed to enable the recipients to visit leading centers in orthopaedic surgery in this country and abroad.

Professional recognition was gladly accorded Ralph Ghormley. His personal friendships were close and lasting. His family life was happy and fruitful, and his final illness was mercifully short. He was a very fortunate man who deserved all his good fortunes and honors.

Our sympathy goes out to his devoted wife and helpmate, Jean McDougall Ghormley, whom he married in 1924, and to his two children, Lieut. Ralph M. Ghormley, U. S. N., and Alice Ghormley Baker, of whom he was very proud. They can indeed be very proud of him.

R.W.J., Jr.; M.C.; and J.S.S.

**ARTHUR STEINDLER, M.D.**
**1878-1959**

The life of Arthur Steindler, one of the greatest and most beloved orthopaedic surgeons of all time, came to a close on July 21.

Dr. Steindler will be sorely missed by ever so many. Meetings of the Academy and the Association will not seem the same without him. At the last meeting of the Academy, his condition then critical, he found the energy to give his Instructional Course and to attend the sessions. His enthusiasm for orthopaedic surgery could be seen in action as he sat in the front row, taking notes and weighing every word of the speaker.

He was born in 1878, attended school in Vienna, and was graduated from the School of Medicine of the University of Vienna in 1902. After his internship, he received orthopaedic training in the hospitals of Vienna under Lorenz, Friedlander, and others until 1907. In that eventful year, he moved to Chicago, where he was associated with Ridlon until 1910. Taking Ridlon's advice, he accepted a professorship in Orthopaedic Surgery at Drake University, Des Moines, Iowa. He served there until 1913, when he moved to the State University of Iowa in Iowa City. He organized the Department of Orthopaedic Surgery and served as its Professor and Head until 1949. From 1949 until the time of his death, he was Distinguished Service Professor Emeritus at the University and Chief of the Orthopaedic Service at Mercy Hospital.

In 1914, the new Professor married Louise Junk, a registered nurse associated with him at Children's Hospital. Their devotion to each other was an inspiration. All through the years, she helped him in a thousand ways. In his numerous complex projects, Louise Steindler was quietly working in the background making his work as easy and as convenient as possible.

Dr. Steindler was honored by one medical society after another. Innumerable foreign

medical associations made him an honorary member. He was particularly proud to have been made an Honorary Fellow of the Royal College of Surgeons. In the International College of Surgeons he served as Regent. In the Medical Reserve Corps of the United States Army he became a Lieutenant Colonel.

He deeply cherished the honor of having been President, in 1933, of The American Orthopaedic Association. The meeting that year was in Washington, D. C. His Presidential Address has been quoted innumerable times and is a model for such addresses. On that occasion he emphasized his dedication to the study of the mechanics of human locomotion. He pointed out that this was virgin soil and that it promised a rich harvest if clinicians would but cultivate it. How he did till this soil in the years that followed! His books on kinesiology are classics. They are libraries in themselves of the biophysics of the locomotor apparatus. Another statement from his presidential address deserves quotation, "We are today less specialistic than we ever were and much more universalists in medicine than our elders a generation ago. In the stricter sense, therefore, the term of orthopaedic surgeon has become inadequate; we should be called orthopaedic physicians". He taught the total-patient concept all through the years.

Dr. Steindler was cosmopolitan. As a linguist he had few peers. A steady stream of foreign visitors and foreign students passed through his department and found no problem if they did not speak English. His versatility was also borne out by his interest in music. He played the piano well, and had an outstanding appreciation of classical music.

His dedication to teaching will live in the hearts of his great following of students. He personally sponsored scores of undergraduate students through the years, many of whom had the privilege of living at his and Mrs. Steindler's beautiful home during their student years. In all probability he has taught orthopaedic surgery to more students than any other man who ever lived. The Arthur Steindler Alumni Association numbers more than 300 and is a close-knit organization. Theirs was a deep devotion to their Chief. Many caught the fire of his inspiration. Teaching the importance of impartial reasoning, he would say, "I would rather be wrong with an impartial reason than prove to be right without one".

His capacity for work was a legend. His strenuous pattern of living caused many to have concern about his health. He would arise at dawn each day for a cold shower and a walk, do what for many would be a day's work before breakfast, then continue working throughout a long day and, after dinner, he would repair to his study and work until late hours. From his busy pen came article after article, book after book. Numerous operations and concepts bear testimony to his genius.

His final book, *Analysis of Pain in Orthopaedic Entities*, was completed a relatively few days before his death. He corrected page proofs when he was so weakened by cancer that he could hardly sit up. This discipline was in keeping with his dedication as a teacher and writer.

He grew older gracefully, but not old, for he never seemed old, just as he had never seemed young. He continued remarkably the same through the years—kindly, modest, gentle, and ever cordial. Those of us who knew him as a friend feel a deep sense of gratitude for that great privilege. He has left a deep impression on orthopaedic surgery and on men which will influence our specialty for decades to come—an enduring memorial to a life well lived.

J.V.L.

# News Notes

Part I examinations of the **American Board of Orthopaedic Surgery** will be held April 13 and 14, 1960, in Nashville, Tennessee, Denver, Colorado, and Philadelphia, Pennsylvania. The deadline for applications is November 30, 1959. Application should be made to the Secretary, Dr. Sam W. Banks, 116 South Michigan Avenue, Chicago 3, Illinois.

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The Twenty-seventh Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held at the Palmer House, Chicago, Illinois, January 23 to 28, 1960.

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A one-year **fellowship in orthopaedic pathology** will be available at the Ochsner Foundation Hospital beginning on July 1, 1960. For information, write to Dr. Mary S. Sherman, Ochsner Clinic, 3503 Prytania Street, New Orleans 15, Louisiana.

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The study by the **Committee on Bio-Mechanics and Implants** of the behavior of implants used in bone surgery is under way. Success of the project depends largely on the number of implants submitted to the Committee. Failing implants discovered at surgery or in the laboratory, along with specimens of the surrounding tissue, should be directed to: Committee on Bio-Mechanics and Implants, The American Academy of Orthopaedic Surgeons, 116 South Michigan Avenue, Chicago 3, Illinois. The Committee requests that information be supplied as to the time elapsing between insertion and failure of implants and, when possible, that roentgenograms be supplied.

**Symposium on Parathyroid Research Trends**

A symposium devoted entirely to the problems of parathyroid physiology and malfunction will be held on the Rice Institute campus, Houston, Texas, on February 3 to 6, 1960. All interested persons are invited to attend. There are no registration fees connected with attendance at the conference. However, pre-registration is requested in order that appropriate facilities can be arranged. Further information and application forms can be obtained by writing to Dr. Roy V. Talmage, Department of Biology, Rice Institute, Houston 1, Texas.

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**M. D. Anderson Hospital and Tumor Institute** of the University of Texas, Houston, Texas, will hold the **Fourteenth Annual Symposium on Fundamental Cancer Research,** "Cell Physiology of Neoplasia", February 25 to 27, 1960. The various subjects to be discussed include morphology of cells, behavior of organelles, submicroscopic structures, cytochemistry, growth phenomena, and biochemical properties of cells. Further information may be obtained by writing: Editorial Office, the University of Texas M. D. Anderson Hospital, Texas Medical Center, Houston 25, Texas.

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The University of Minnesota announces a **Continuation Course in Orthopaedics for General Physicians** which will be held at the Center for Continuation Study from November 16 to 18, 1959. Treatment of common fractures and associated orthopaedic problems will be stressed. Guest speaker will be Dr. Dana M. Street, Professor of Orthopaedic Surgery, University of Arkansas School of Medicine, Little Rock. The course will be presented under the direction of Dr. John H. Moe, Professor and Director, Division of Orthopaedic Surgery.

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The College of Physicians and Surgeons, Columbia University, New York, N. Y., announces that its **Fourth Annual Postgraduate Course in Orthopaedic Surgery** will be held at the Columbia-Presbyterian Medical Center, November 9 to 13, 1959, under the direction of Dr. Frank E. Stinchfield. Further information and application blanks may be obtained from the Office of the Dean, College of Physicians and Surgeons, 630 West 168th Street, New York 32, N. Y.

# Book Reviews

YEAR BOOK OF ORTHOPEDICS AND TRAUMATIC SURGERY. 1958-1959 Year Book Series. Edited by Edward L. Compere, M.D., F.A.C.S., F.I.C.S. With a Section on Plastic Surgery edited by Neal Owens, M.D., F.A.C.S., F.I.C.S. Chicago, The Year Book Publishers, Incorporated, 1959. $7.50.

The appearance of this 1958-1959 volume with its familiar format and binding is the moment to bid *ave atque vale!* to Dr. Edward L. Compere who, after twelve years, is laying aside his editorial mantle. Many of the most useful "tools of the trade" grow so familiar that we rarely stop to think of what goes into them. The files of more than eighty journals, national, regional, and local, domestic and foreign, have been scanned to produce this compact volume. Few of these are orthopaedic journals, many are not surgical journals, all have something of value for the orthopaedic surgeon. It is the work of selection even more than that of collection that make the Year Books valuable, that enable them to call attention to orthopaedic information that the most omnivorous reader would hardly find for himself.

INJURIES AND SURGICAL DISEASES OF THE ISCHIUM. Henry Milch, M.D. New York, Hoeber-Harper, 1958. $10.50.

This book represents a monographic treatment of a very restricted subject. It is a difficult task when one considers that the ischium represents less than one-third of the hip bone. Having so defined the extent of his subject, the author has not actually confined himself to the ischium. Much of the book concerns other portions of the acetabulum, measurements, and locations of nerves and vessels about the hip, which have no apparent relationship to the ischium *per se*.

The anatomy section adds little of new information, but relies heavily on non-original illustrations, many of which are not well labeled. The anatomical relationships of the urethra, internal pudendal artery, and pudendal nerve are inadequately described to obtain an understanding of the mechanism of injury to these important structures by fractures of the ischium.

Much of this book is a bibliographical review of uncommon entities such as ischial apophysiolysis, periostitis of the ischium, gracilis exostosis, ischium varus, and ischial bursitis, which will be interesting to some readers. An excessive use of eponyms in this section may be found confusing since not all of them are listed in the bibliography.

The most informative and useful material appears in the chapters on osteomyelitis, tumors, and decubitus ulcers. However, none of these conditions are specific problems of the ischium alone. It is not easy to justify separate treatment in this manner of a bone which is so closely related to the other portions of the bony pelvis unless, in condensed form, it were part of a more general textbook. The author's surgical approach to the ischium described in the last chapter is interesting and valuable.

*Wayne O. Southwick, M.D.*

CLINICAL ENZYMOLOGY. Edited by Gustav J. Martin, Sc.D. Boston, Little, Brown and Company, 1958. $6.00.

Enzymology or dynamic biochemistry, currently in a logarithmic growth phase, has invaded every area of biology. All efforts to summarize the progress of this science suffer from having to make arbitrary selections of topics. Such condensations are inevitably somewhat out of date, no matter how rapid the publication.

This book covers selected contributions of enzyme chemistry to medicine. The opening and concluding chapters by Dr. Martin deal with generalizations about the nature of enzymes and enzyme catalyzed reactions. Three chapters contributed by M. J. Sullivan, J. M. Beiler, H. Tanyol, and W. M. Swain develop the rational principles and practical considerations of parenteral enzyme therapy, especially with the proteolytic enzymes. The section on the parenteral use of enzymes is a masterful compilation of information not previously available in a single volume.

The chapter by G. V. Rossi on the diagnostic use of enzymes is a thorough and critical summary of techniques already well established in clinical pathology. It is disappointing that the discussion stops short of speculations about the exciting diagnostic possibilities that may emerge from the current systematic investigations of the serum levels of the more ubiquitous intracellular enzymes, the transaminases, glycolytic enzymes, and others.

The chapters by Dr. Martin are written from a highly speculative point of view with the arguments of the theoretical physicist in prominence. They form a provocative essay for the reader already well grounded in the fundamentals of the science. However, even a much larger

volume than this would be unable to present enough background material to make some of these advanced concepts comprehensible to the unspecialized reader.

The book can be highly recommended to physicians specifically interested in the parenteral administration of enzymes and to those with more than a superficial familiarity with biochemistry.

*Charles H. DuToit, M.D.*

METALS AND ENGINEERING IN BONE AND JOINT SURGERY. Charles Orville Bechtol, M.D., Albert Barnett Ferguson, Jr., M.D., and Patrick Gowans Laing, M.B., B.S., F.R.C.S. Baltimore, The Williams and Wilkins Company, 1959. $8.00.

The growing importance of the use of metallic implants in surgery undoubtedly will attract many readers to this small book. It is the first volume in English, to my knowledge, devoted entirely to the surgical use of metals. As such, the many relevant metallurgical facts which the authors have collected will undoubtedly prove interesting to all orthopaedic surgeons and to many others. In some measure, the purpose of the book is achieved, namely, to gather the pertinent biological and engineering principles so that surgeons may understand better the fundamental, often conflicting, influences which affect present practice. One should not expect a thorough exposition of modern concepts in the many disciplines involved. There are far too many details in the diverse fields for comprehensive examination of either facts or principles in any single area. The authors' references to the literature show that adequate texts do not exist for several of the main topics with which they are concerned: corrosion, composition and structure of the newer alloys, and modern manufacturing practice with reference to these alloys. Again, even though a chapter is devoted to the history of the use of metals implanted in the body, the majority of the references are less than ten years old and the older ones have little more than academic interest.

The book will serve as an introduction to many who have not realized the ramifications of the subject. It will show them the necessity for broader basic studies not only in the newer fields of technology represented by alloys being developed for corrosion resistance, but also in older knowledge of the craft, which tends to be forgotten in the modern emphasis on novelty and progress. Thus some common rules of good carpentry, here described as engineering principles, some practices in manufacture of tools, screws, and the like, some references to proper specifications and inspection of surgical implants, and some elements of the craft of surgery as developed over the years, are important components of this book. The book serves, thus, to introduce important metallurgical and mechanical information to the orthopaedic profession. Undoubtedly, more comprehensive treatises are needed to supplement and clarify the data given.

*Jonathan Cohen, M.D.*

TRANSPLANTATION OF TISSUES. Vol. II. Lyndon A. Peer, M.D., (Editor). Baltimore, The Williams and Wilkins Company, 1959. $20.00.

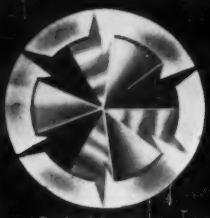
In this volume, Dr. Peer continues the review of the problem of tissue transplantation begun in Volume I. (J. Bone and Joint Surg., **38-A**: 473, Apr. 1956).

Volume II is divided into twelve parts, each consisting of a discussion by an outstanding contributor in that special field. After consideration of cells and tissue in general, specific attention is given to the transplantation problems of skin, cornea, fat, nerves, teeth, blood vessels, endocrine glands, organs (including kidney), peritoneum, and tumors. The final chapter concerns the problems of tissue culture and its role in the study of transplantation.

The tissues of special concern to the orthopaedic surgeon, namely cartilage, bone, fascia and tendon, and muscle were dealt with in Volume I. To one interested in the general problem of tissue homotransplantation, however, this book will be of certain value, not only for the text, but also for the exhaustive bibliography accompanying each section. As in Volume I, complete agreement with all statements made cannot be expected, as is illustrated by Dr. Peer's "cell survival theory". Of particular interest, in my opinion, are the sections on the zoological laws of transplantation by Dr. P. B. Medawar, on skin grafts by Dr. Blair Rogers, on nerve transplantation by Dr. Sterling Bunnell, and on tumor transplantation by Dr. E. J. Eichwald.

Dr. Peer is to be commended again for organizing a comprehensive review of the extensive literature in this very rapidly growing, but still pioneering field of tissue transplantation.

*Paul H. Curtiss, Jr., M.D.*



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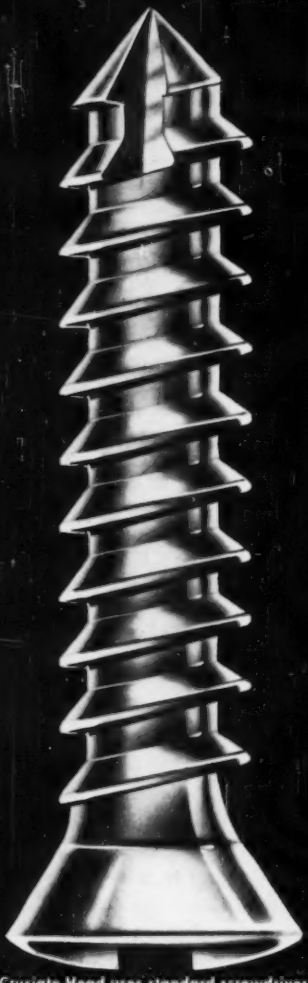

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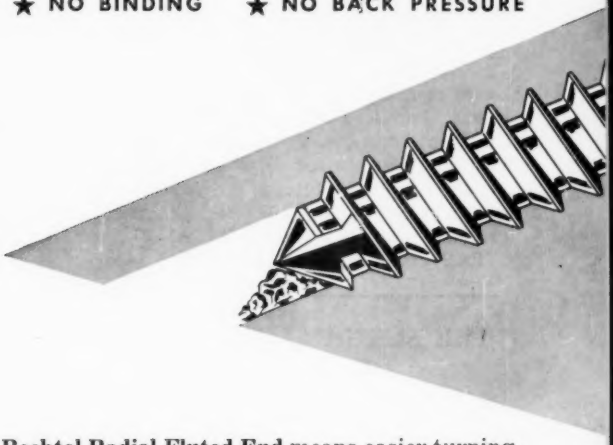

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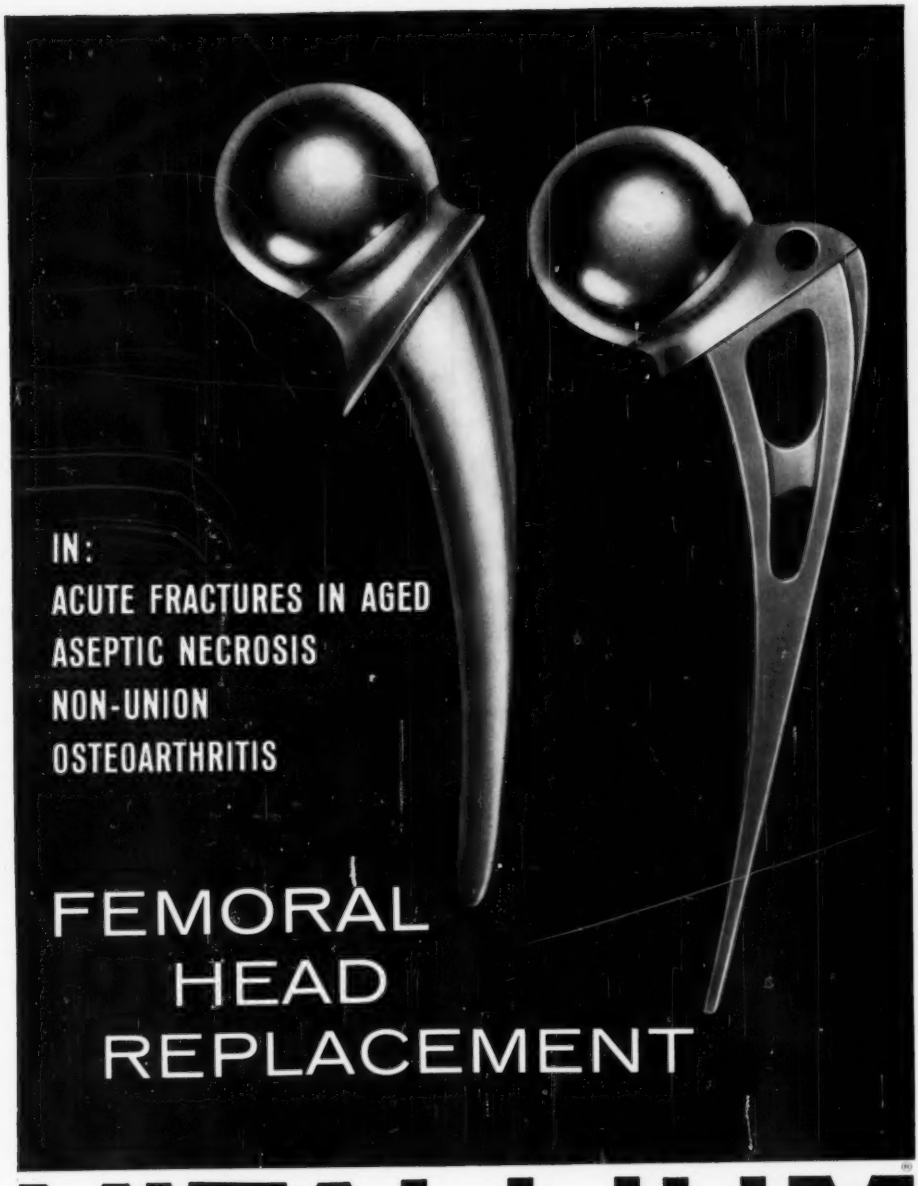


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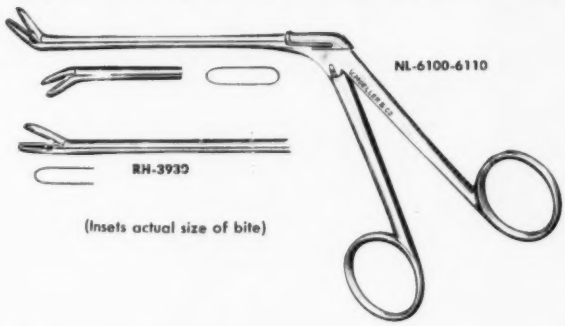


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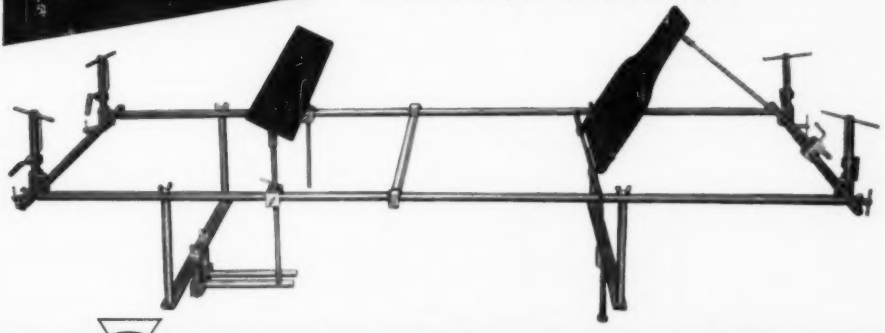

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